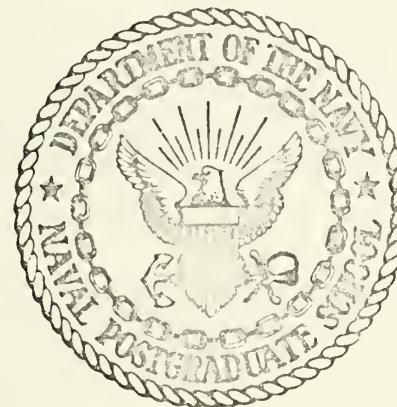


A GENERAL PROBLEM DESCRIPTOR
FOR
COMPUTER ASSISTED INSTRUCTION

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THEESIS

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FOR
COMPUTER ASSISTED INSTRUCTION

by

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June 1971

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A General Problem Describer
for
Computer Assisted Instruction

by

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN COMPUTER SCIENCE

from the

NAVAL POSTGRADUATE SCHOOL
June 1971

ABSTRACT

Currently in computer assisted instruction systems a number of problems are presented to each student during a problem session and each individual problem is specified by the author of the session. A better approach might be to provide the author with a language in which he can describe the general type of problem he wants his students to be taught and let the machine generate the specific problems. This would relieve the teacher of the task of writing out a whole series of problems for each general concept he wishes to teach. This thesis presents a subset of English and mathematical notation which the teacher can use to describe a general problem type. The PROBLEM DESCRIPTION PROCESSOR accepts the general problem description and produces a low level language which is used by the PROBLEM DESCRIPTION INTERPRETER to produce specific problems. This system works for fourth grade arithmetic problems and could be extended for use in other areas of instruction.

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I. INTRODUCTION

As the population of the United States increases and as technology and behavior become more complex, the need for quality education in schools and universities becomes more compelling. But the need is not limited to quality. The quantity of instruction is being hard pressed to maintain the same growth rate as enrollments. In California, the State Superintendent of Public Instruction, Wilson Riles, has stated that student enrollments are higher this school year than they were last year, but the state has 9000 fewer teachers. This means that other ways must be found to maintain quality in the United States.

Computer assisted instruction is one of the possible ways in which some of the critical areas of education may be improved. Some of the areas which need improvement are providing individualized instruction and relieving the teacher of administrative tasks. The research that has been done for this thesis and computer assisted instruction in general has only scratched the surface in trying to get rid of these problems.

Since the effectiveness of a learning task depends on the efficiency of communication it achieves, the focus of learning should be narrow; the learner should not be required to give significant attention or effort to behaviors irrelevant to the instructional goals; and the

quantum of learning should be kept small enough so that the learning situation can be properly and confidently evaluated by the learner. At the same time the learning situation should be rich enough to convey the exact characterization in minute detail.

Conventional instruction systems depend on humans to carry out the crucial functions of response evaluation and motivation of the student. Where learning tasks can be devised that use a computer terminal, interactive computer assisted instruction could, in principle, take over the functions of evaluation and motivation of students if a task evaluation algorithm and an algorithm of control can be made. Numerical evaluation systems are of special value and importance because they lend themselves to mathematical modeling.

This research is an attempt at the design and implementation of a very small section of computer assisted instruction which describe a general type of problem and specifies the constraints on each problem. The idea is to be able to use a more natural language to describe a general type of fourth grade arithmetic problem. It is felt that the more the problem description language approximates English the easier it would be for a non-programmer to use. The language presented in this thesis is still somewhat restricted because it consists of only a subset of English and has a somewhat set form. The overall system provides an interface between the computer and the teacher for the description, selection, and presentation of problems to students.

II. BACKGROUND

The field of instruction technology presents a rather complex picture. Any attempt at reviewing this new and rapidly changing field would be incomplete and approximate at best. An instructional system includes the following elements: learner, materials, monitor, author-teacher, and administrator. The picture becomes more complex with the addition of other students, teachers, teaching assistants, special projects, and outside reading. The dynamic interaction of materials, strategies, and communication channels over time must be considered in any complex analysis. There are a number of basic and distinct, though interdependent, aspects or functions of computer assisted systems.

A common view is that computer assisted instruction is an automated form of programmed instruction. It should be no surprise to find that many implementations of computer assisted instruction use this simplistic approach of automating the existing methods. Other "teaching machines" permit some changes in the format. But with the capabilities of computers and display devices which are available, one should not be constrained to variations of the earlier paper and pencil format. Instead of simply automating programmed instruction, new computer based instructional systems should fully exploit the capabilities of the computer. This is being investigated by this and other research at the Naval Postgraduate School.

In this section, various modes of computer assisted instruction will be discussed as well as what can, in general, be done with computers in education.

A. MODES OF COMPUTER ASSISTED INSTRUCTION

There are different areas in which computer assisted instruction can operate. These have been widely discussed in the literature. In this section five general types of computer assisted instruction systems are discussed: drill and practice, inquiry, tutorial, problem solving, and author.

1. Drill and Practice

The computer is used to present a sequence of spelling or arithmetic problems and the system allows the student numerous opportunities for response. The introduction of concepts and new ideas is handled in conventional fashion by the teacher. In the case of elementary mathematics each student would receive daily a certain number of exercises, which would be automatically presented, evaluated, and scored by the computer program without any interference by the teacher. These exercises can be presented on an individualized basis, with the brighter students receiving exercises that are harder than the average, and the slower students receiving easier problems. In using a computer in this way, it is not necessary to decide which category a student fits in at the beginning of the school year and a student does not need to stay in the same category for the entire year. In this context, category means both the grade level of the student and

the difficulty of problem he can work. Individualized drill and practice work is suitable to most of the elementary subjects which make up the curriculum. Typical parts of the curriculum which benefit from standardized and regular drill and practice exercises are elementary mathematics, elementary science, and the beginning work in foreign language.

2. Inquiry

This mode has often been called information retrieval and can easily be used by computer assisted instruction to answer general questions asked by a student. In this mode the student uses a natural language. He asks questions which are addressed to the system. The system typically processes the questions using key-words, hashing codes and search algorithms to retrieve an answer. Systems Development Corporation has a program called CONVERSE. This program has been designed to provide answers to questions posed in a limited subset of English. Using an existing data management system, CONVERSE translates an English question into one or more file-searching procedures. If complete translation is not possible, the program provides the user with information that may help him in rephrasing his questions into acceptable English terms.

A system has been built that attempts to answer students' questions from an encyclopedia which has been placed in the computer's memory. The first step in answering the question is to make a search for the smallest unit of text in the data base, preferably a sentence containing the

intersection of the greatest number of content words contained in the question. A simple information score is used to weight some words more heavily than others in selecting potential answers. The highest scoring answers are then retrieved from the tape on which the original text was stored, for the students' answer. The approach is to successively filter out more and more irrelevant information, leaving only statements which have the highest probability of being answers to the question.

3. Tutorial

This is a level of instruction that not only involves questions and answers between the computer and students during the presentation of instructional material, but may involve other modes of computer assisted instruction. The other modes become classes of instructional experience that can comprise a more general educational experience for the students. The computer program takes over the responsibility both for presenting a concept and for developing skill in its use. The intention is to approximate the interaction between a patient tutor and an individual student. The program has to have enough flexibility to ensure that the bright students do not become bored with endless repetitive exercises and ensure that the slower students do not become discouraged with initial failures. As soon as the student has a clear understanding of a concept on the basis of his handling of a number of exercises, he is moved on to a

new concept and new exercises. The formulation of teaching strategies is the biggest problem facing the authors of this mode.

4. Problem Solving

Problem solving can be looked upon in two different ways. The first is the use of a computer to solve quantitative problems and the student uses a language like FORTRAN or BASIC to accomplish his purpose. He writes a program and enters his data. But this is a narrow approach when looking at the second method which is a considerably more complex system involving the modelling of human problem solving capability. This type of system is best represented by the Newell, Shaw, and Simon work in 1959 on General Problem Solver. A set of complex means-ends analysis routines make up the main part of the program.

5. Author

This is the most primitive in the state of development. The system's capability depends upon its ability to generate specified kinds of materials, to load them on the system, to select the best modes of computer assisted instruction, and to present the material in modules which minimize the teaching-learning effort. Within instructional modes, a number of variations are still possible, so an algorithm must be used to select not only the mode of instruction but also particular variations to use with it. To locate within a mode the particular variation that is wanted, there have to be contingency rules that depend upon who the student is

and how he has performed. This differs from the tutorial mode in that the computer in conjunction with the student decides what is to be presented.

B. COMPUTERS IN EDUCATION

The nature of a learning activity may be more or less artificial, depending upon the extent to which the behavior being developed is a subskill of the final behavior or a rough approximation to it. In any case the learning task itself has content and involves behaviors that are irrelevant to the final instructional goals, but are necessary for purposes of doing the task; examples of such secondary skills are the use of a keyboard, the format rules of messages, the procedures used in a test administration. Computer assisted instruction systems should be carefully designed to provide flexible, interactive capabilities without introducing too much of this type of overhead.

Recently elementary mathematics has been reorganized around the idea of presenting fundamental mathematical concepts which logically build upon each other. For example, the concept of a set is presented, addition is described in terms of sets, etc. This approach lends itself very nicely to computer directed tutoring because new concepts and tutoring hints can be based upon more primitive concepts.

A computer-based system allows interim and sometimes automatic decisions in the course of a session. In addition to reducing the total elapsed time required for execution

of a session, the computer can keep a record of the full interaction with the student with three major gains. The record of performance for the teacher allows easy and pinpointed experimentation with alternate ways of presenting material of various sorts to various students, thus improving understanding and practice in education. A record of what the student has learned and his particular learning features can govern the rules of thumb used by the tutoring program. This record shows the teaching methods that are the best for the individual student. It would show such things as: whether ideas are best presented first by example or introduced initially as general principles, whether small steps and repetition or great mental strides are needed, or whether visual or auditory presentation is most helpful. The third gain of the performance record is a way of determining if a student has in fact demonstrated a certain level of comprehension. The computer can teach and independently certify achievement.

III. DESIGN OF THE PROBLEM DESCRIBER

The concepts which every computer assisted instruction system should use are the ideas of students moving at their own pace, individualized instruction, and a more flexible school system. If these ideas are used in conjunction with a computer system which has complete graphics terminals, they could enhance a number of areas such as arithmetic, ~~geometry~~, ~~geometry~~,

set theory, algebra, etc. This thesis concerns itself mostly with fourth grade mathematics, but the ideas could be easily extended to cover these other areas.

In looking at computer assisted instruction there are various routes which can be taken in the development of a tutorial system. One of these routes and the most basic is to look at one specific problem at a time. The teacher would tell the computer the exact problem that he wants. A sample set of addition problems with no carries would be:

$$(1) \quad \begin{array}{r} 27 \\ +52 \end{array} \quad \begin{array}{r} 31 \\ +45 \end{array} \quad \begin{array}{r} 72 \\ +17 \end{array} \quad \begin{array}{r} 51 \\ +38 \end{array}$$

This method requires the teacher to make up a series of problems for each concept to be covered. Another disadvantage of this method is that it does not lend itself to much variety of problem presentation because each student works the same set of problems. This is essentially the same thing as writing out a set of problems on a spirit master, having it reproduced, and handing it out to the students to be worked. Without variety the bright students become bored with much repetition and the slower students will easily become discouraged when they can not answer some of the questions.

If a teacher had a language available which provided him with a method of describing general types of problems he could describe a problem type and let the machine produce specific problems which demonstrate the desired concept. In this way a terminal session could be designed to generate a variable

number of problems depending upon how quickly the student learned the material. Each time a problem of a given type is desired a reference is made to the proper problem description and the machine calls on a random number generator to produce a specific problem. Notice that, since a random element is built into this approach, different students will see different problems - all of which are examples demonstrating the concept included in the problem description. The teacher describes the type of problem once and refers to this description as often as he likes.

There are a number of different ways a language could be constructed to describe a type of problem. The rest of this section will discuss a series of four possible languages: (1) a low level language involving detailed specifications for each digit; (2) a higher level language which allows some mathematical notation; (3) a higher level language which allows a subset of English and mathematical notation; and (4) full English. Two example specifications of problem types will be used in this discussion: (1) an addition problem without carries; and (2) an addition involving one carry in the tens column.

The low level language requires that the number of digits and the limits on each digit be explicitly stated. For example the addition problem without carries would be described as follows:

(2) $X_4X_3X_2X_1 + Y_3Y_2Y_1 = \text{answer}$
 $X_4 = \text{RANDOM DIGIT (0 to 9)}$
 $X_3 = \text{RANDOM DIIT (0 to 9)}$
 $X_2 = \text{RANDOM DIGIT (0 to 9)}$
 $X_1 = \text{RANDOM DIGIT (0 to 9)}$
 $Y_3 = \text{RANDOM DIGIT (0 to (9 - value of } X_3)}$
 $Y_2 = \text{RANDOM DIGIT (0 to (9 - value of } X_2)}$
 $Y_1 = \text{RANDOM DIGIT (0 to (9 - value of } X_1)$

The first line indicates that the problem is an addition problem involving a 4-digit number and a 3-digit number. The remaining lines explicitly state the procedure to be used to generate values for these digits. Specific problems which the computer might generate for this description might be:

$$\begin{array}{r} 2791 \\ +103 \end{array} \quad \begin{array}{r} 5411 \\ +536 \end{array}$$

The addition problem which includes a carry in the tens column would be described as follows:

(3) $X_4X_3X_2X_1 + Y_3Y_2Y_1 = \text{Answer}$
 $X_4 = \text{RANDOM DIGIT (0 to 9)}$
 $X_3 = \text{RANDOM DIGIT (0 to 9)}$
 $X_2 = \text{RANDOM DIGIT (0 to 9)}$
 $X_1 = \text{RANDOM DIGIT (0 to 9)}$
 $Y_3 = \text{RANDOM DIGIT (0 to (8 - value of } X_3)}$
 $Y_2 = \text{RANDOM DIGIT ((10 - value of } X_2) \text{ to 9)}$
 $Y_1 = \text{RANDOM DIGIT (0 to (9 - value of } X_1)$

Specific problems might be:

$$\begin{array}{r} 8547 \\ +271 \end{array} \quad \begin{array}{r} 2563 \\ +156 \end{array}$$

Looking at a higher approach, why not describe the general problem and the limits on the digits in mathematical notation. This will add more flexibility and make things a little easier for the teacher. The computer program would be more involved, but it could still generate problems of

the type specified. Using mathematical notation the addition problem with no carries would look like this:

$$(4) \quad X_4 X_3 X_2 X_1 + Y_3 Y_2 Y_1 = \text{Answer}$$
$$Y_3 \leq 9 - X_3$$
$$Y_2 \leq 9 - X_2$$
$$Y_1 \leq 9 - X_1$$

The problem which has carries in the tens position would be:

$$(5) \quad X_4 X_3 X_2 X_1 + Y_3 Y_2 Y_1 = \text{Answer}$$
$$X_2 \geq 1$$
$$Y_3 \leq 8 - X_3$$
$$Y_2 \leq 10 - X_2$$
$$Y_1 \leq 9 - X_1$$

Notice that this method should be relatively easy for the elementary teacher to use, but it is still not quite the way one teacher would describe a general type of problem to another teacher.

By using a small subset of informal English with mathematical notation, the concept of general problem description can be broadened even more. What English phrases are needed to be able to state a general problem? Typical phrases are "carries in tens place," "borrows in tens place," and "carries in position two." In order to specify the direction the problem is to be worked, "vertical problem direction," "vertical," "hor," or something along these lines is needed. With this additional flexibility the first example could be specified as follows:

$$(6) \quad X_4 X_3 X_2 X_1 + Y_3 Y_2 Y_1 = \text{Answer}$$

No carries with a vertical problem direction.

or

$$(7) \quad X_4 X_3 X_2 X_1 + Y_3 Y_2 Y_1 = \text{Answer}$$

Vert no carries.

The second example could be:

(8) $X_4X_3X_2X_1 + Y_3Y_2Y_1 = \text{Answer}$
Carries in tens place hor.

A problem with complex constraints may be written as:

(9) $X_4X_3X_2X_1 + Y_3Y_2Y_1 = \text{Answer}$
Horizontal
 $X_4 > X_3$
 $X_3 > X_2$
 $X_2 > X_1$
 $Y_3 < 9 - X_3$
 $Y_2 \neq X_2$

The highest level of problem description which can be achieved is to be able to have the full use of English. This gives the average elementary teacher who is a non-programmer of computers a more flexible and understanding way of describing problems. A problem description including administrative information, tutoring hints, etc., might be described in English as:

(10) Generate ten addition problems with carries in tens place. First, show the student two examples. If there are any errors in the student's work, demonstrate how the problem should have been worked.

Or another problem description might be:

(11) Demonstrate two addition problems with carries in tens place presenting the problem horizontally then generate ten of the same type of problems for a quiz.

This method is only possible when a language processor is developed which will accept valid English sentences and convert these sentences into the low level language.

IV. IMPLEMENTATION OF THE PROBLEM DESCRIPTOR

At the beginning of the implementation phase, a decision had to be made as to which language to use. There are many languages available but the one chosen for this work in the construction of a general problem describer was XPL. One of the main reasons XPL was chosen is that it has a syntax directed skeleton compiler with an associated syntax analyzer. The syntax analyzer is used to construct tables which this skeleton compiler uses to make reduction decisions during compilation.

The most desirable way to describe a general problem is one which has the full use of English. For practical considerations, the language developed in this thesis uses a subset of English and mathematical notation (i.e., the third language mentioned in Section III). In order to implement a system like this the following is needed: (1) an interpreter that accepts a language based on the low level language in Section III; and (2) a language processor which changes the subset of English and mathematical notation into the low level language. The flow of information which is accomplished by this system is shown in Figure 1.

A. PROBLEM DESCRIPTION INTERPRETER

The PROBLEM DESCRIPTION INTERPRETER interprets the description of problem type written in the low level language and produces a specific problem fitting the description.

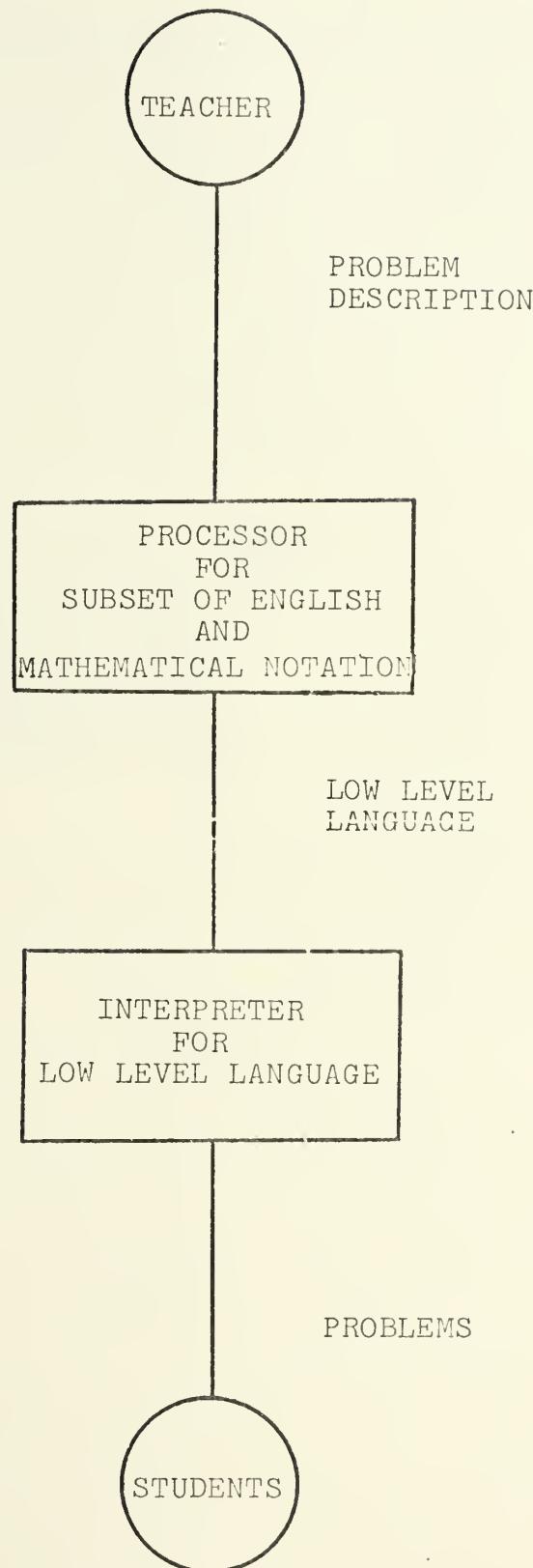


Figure 1. Flow of Information

The low level language was intentionally designed so that it could be easily interpreted by the machine. Although it is not normally done, a teacher who was accustomed to the system and had a knowledge about problem construction could describe his own problems if he were so inclined. The syntax for this language is described in Appendix C. An example of an addition problem with no carries in this language would look like this:

(1) X4X3X2X1 + Y3Y2Y1 = ANSWER
X4 = A_NUMBER(0->9)
X3 = A_NUMBER(0->9)
X2 = A_NUMBER(0->9)
X1 = A_NUMBER(0->9)
Y3 = A_NUMBER(0->9-X3)
Y2 = A_NUMBER(0->9-X2)
Y1 = A_NUMBER(0->9-X1)
HOR;

As was stated above the basis for the development of the interpreter was XPL SKELETON which is described in Ref.1⁴. The general relations among the major procedures and GET_VALUE_OF are shown in Figure 2.

GET_VALUE_OF uses a set of array variables: SYMBOL, which holds every identifier that appears in the problem; VALUE_OF, which holds the single digit value of its corresponding identifier; NUMBER_OF, which is a character string that delimits the value its identifier can assume; FLAG, which tells if NUMBER_OF contains a valid numerical string or not; VAL_FLAG, which tells if VALUE_OF requires a random digit to be generated or not. Once the values are obtained for each identifier, HOR or VERT prints out the problem to be worked.

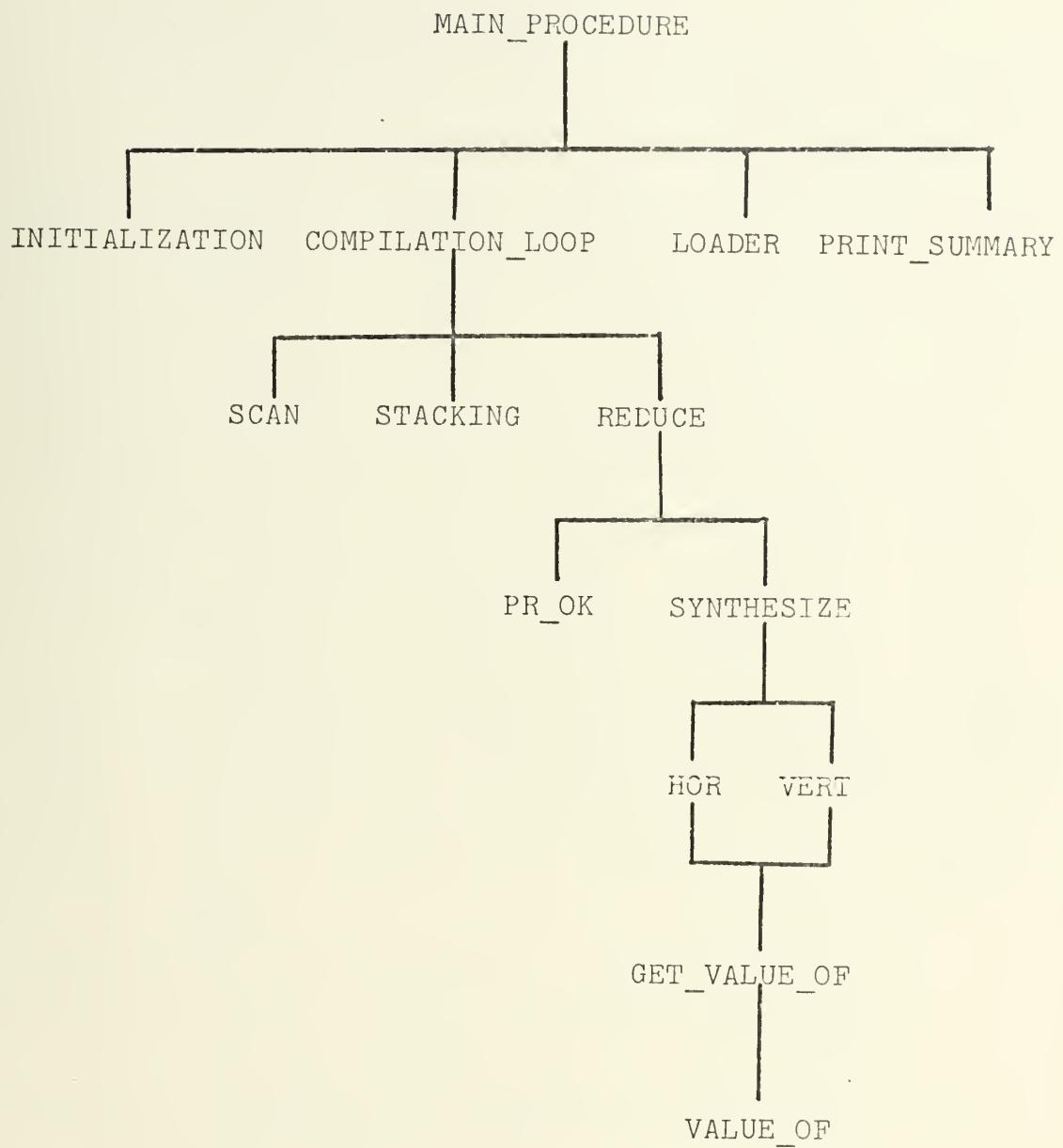


Figure 2. Relations among Major Procedures

B. PROBLEM DESCRIPTION PROCESSOR

After developing the PROBLEM DESCRIPTION INTERPRETER, a processor was developed that would accept a subset of English and mathematical notation and produce the low level language of the interpreter. The language was written for the processor with the idea that the PROBLEM DESCRIPTION PROCESSOR would be expanded to handle problem descriptions of geometry, set theory, geometric construction, and trigonometry problems if the system was ever used in conjunction with graphics terminals. Some examples of this language are:

(2) $X4X3X2X1 + Y3Y2Y1 + \text{ANSWER VERT}$

This is the simplest problem that can be stated. The problem would be shown as a standard addition problem of two numbers with a line drawn under them such as:

(3)
$$\begin{array}{r} 6037 \\ \underline{592} \end{array}$$

The following is a standard subtraction problem:

(4) $X4X3X2X1 - Y3Y2Y1 = \text{ANSWER HOR}$

It will be presented to the student like this:

(5) $7452 - 231 = \underline{\hspace{2cm}}$

The following example

(6) $W4W3W2W1 + X4X3X2X1 = \text{ANSWER HOR CARRIES IN ONES PLACE}$

would generate a problem which would have a carry from ones place to tens place.

The same type of problem could be generated by:

(7) $W4W3W2W1 + X4X3X2X1 = \text{ANSWER HOR}, W1 + X1 > 9$

The example:

$$(8) \quad Y4Y3Y2Y1 + X3X2X1 ? Y4Y3Y2Y1 + X3X2X1$$

requires the student to figure out what the relationship between both sides of the equation is.

$$(9) \quad X4X3X2X1 + ANSWER = Z5Z4Z3Z2Z1 \text{ VERT. } Z5 > 0$$

The student will have to perform a subtraction operation in order to find the answer. This problem specifies that the problem is to be presented vertically.

The number of constraints on the individual digits must be less than 32 and have commas separating each of them.

An example which uses a number of constraints might be:

$$(10) \quad X4X3X2X1 + Y4Y3Y2Y1 = ANSWER \text{ HOR. } Y4 > Y3, Y3 > Y2, Y2 \geq Y1, X3 \neq Y3, X2 + Y2 > 9, X4 = Y4, X1 = 5.$$

XPL SKELETON is used as a basis for the processor in much the same way as it was for the interpreter. In SKELETON, SYNTHESIZE enters the constraint equation identifiers which have not been entered in the symbol table and then calls RESOLVE which looks at the constraints, manipulates them into a usable form, and produces code for the interpreter. The first manipulation is done by placing the constraint equations into the following order: type zero is <identifier><relation> <number>, type one is <identifier> <relation> <identifier>, type two is <identifier> + <identifier> <relation> <number>, type three which is not implemented in the problem description is <identifier> + <identifier> <relation> <identifier>. After this has been done to Example (10) above, it would look like this:

(11) $X_4X_3X_2X_1 + Y_4Y_3Y_2Y_1 = \text{ANSWER HOR.}$
X₁ = 5
Y₄ > Y₃
Y₃ > Y₂
Y₂ >= Y₁
X₃ ≠ Y₃
X₄ = Y₄
X₂ + Y₂ > 9

The problem is again manipulated and the relations are all changed to either equal, less than, less than or equal or not equal. After this has been accomplished the problem would be:

(12) $X_4X_3X_2X_1 + Y_4Y_3Y_2Y_1 = \text{ANSWER HOR}$
X₁ = 5
X₄ = Y₄
Y₃ < Y₄
Y₂ < Y₃
Y₁ <= Y₂
X₃ ≠ Y₃
9 < X₂ + Y₂

After this manipulation, the code for the interpreter is generated. This is done by taking the identifiers which already have been entered in the symbol table and branching to different code generating procedures depending on the type classification and its relation. After processing all of the constraints, code is generated for any digits that are not limited by constraints. This code is placed before the code that was generated by the constraint equations. The complete code file of low level language would be:

(13) $X_4X_3X_2X_1 + Y_4Y_3Y_2Y_1 = \text{ANSWER}$
Y₄ = A_NUMBER (0->9)
X₁ = A_NUMBER (5)
X₄ = A_NUMBER (Y₄)
Y₃ = A_NUMBER (0->Y₄)
Y₂ = A_NUMBER (0->Y₃)
Y₁ = A_NUMBER (0->Y₂)
X₃ = A_NUMBER (0->Y₃₋₁, Y_{3+1->9})
X₂ = A_NUMBER (9-X_{2->9})
HOR;

If there are any errors in the problem description they will be printed out by the mechanism of SKELETON. If any conflicts between the constraint equations arise the first constraint will take precedence over the second constraint. An excerpt from a code file which has conflicts may look like this:

```
(14)  X1 < Y1
      X2 = 5
      X4 < 6
      X1 = 9-Y1
```

In this case X1 would take on a value less than the value of Y1 instead of a value in the range from 0 to 9 minus the value of Y1.

V. CONCLUDING REMARKS

This research has demonstrated that a higher level language for describing general types of problems can be implemented. Although the system which was developed concerned itself with fourth grade arithmetic, the general approach could easily be expanded to include other areas of instruction. In general, the system represents one step toward providing a relatively easy language in which teachers can design computer assisted instruction systems which do more than present a fixed set of problems, correct them, and record the progress of the various students.

The system was designed to be included as a part of a flexible tutoring system, but it could certainly be incorporated in any computer assisted instruction system which involves general types, or classes of problems. For example, a drill and practice system could very nicely be designed around such a higher level language for problems.

The hardware is available now for large computer assisted instruction systems, but there still remains a considerable amount of software development before such systems can be economically used. This research is a contribution toward this software development.

APPENDIX A

Format description of language for communicating with the PROBLEM DESCRIPTION PROCESSOR.

The meta-symbols used in the description of the language serve the following functions:

`::=` is used to indicate a definition

`|` is used to indicate alternate definitions

`< >` are used to enclose items which are elements of the meta-language which describe the elements of the PROBLEM DESCRIPTION PROCESSOR language

`<teachers statement> ::= <teachers definition>`

`<teachers definition> ::= <problem definition> | <teachers definition> <problem definition> | <function definition> | <teachers definition> <function definition> | <definition definition> | <teachers definition> <definition definition>`

`<problem definition> ::= <set operations> | <geometry> | <statistics and probability> | <trigonometry> | <arithmetic operations> <problem construction> <problem constraints> | <arithmetic operations> <problem construction>`

`<arithmetic operations> ::= <expression> <relation> <expression>`

`<expression> ::= <term> | <expression> + <term> | <expression> - <term> | + <term> | - <term>`

`<term> ::= <primary> | <term> * <primary> | <term> / <primary>`

`<primary> ::= <number> | <identifier> | (<expression>) | ANSWER`

`<relation> ::= = | < | > | ≠ | × | × | <= | >= | ?`

`<problem direction> ::= VERT | VERTICAL | HORIZ | HGT | HORIZONTAL`


```

<problem construction> ::= <problem direction> CARRIES IN
                           <identifier> PLACE | <problem
                           direction> CARRIES IN POSITION
                           <number> | <problem direction>
                           BARROWS IN <identifier> PLACE
                           <problem direction> BARROWS IN
                           POSITION <number> | <problem
                           direction>

<problem constraints> ::= <problem constraints right> |
                           <problem constraints> <problem
                           constraints right>

<problem constraints right> ::= <left problem constraint>
                               <number> | <left problem
                               constraint> <identifier>

<left problem constraint> ::= <middle constraint> <identifier>
                               <relation> | , <identifier>
                               <relation>

<middle constraint> ::= , <identifier> +
                        

<set operations> ::= <union> | <intersection> | <complement>
                     | <disjoint> | <equal>

<geometry> ::= <metric> | <non-metric>

<statistics and probability> ::= <measure of central tendency>

<metric> ::= <area of regions>

<non-metric> ::= <lines, points and curves> | <planes> |
                  <angles> | <polygons> | <circles> |
                  <construction>

<measure of central tendency> ::= <average> | <range> |
                                    <mode> | <median>

```


PROBLEM DESCRIPTION PROCESSOR

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```

*/          /* MAXSYMBOLS IN TABLE
DECLARE      LITERALLY '32';      /* MAXSYMBOLS IN TABLE
MAXSYM      LITERALLY '1';      /* MAXSYMBOLS IN TABLE
EQUALS      LITERALLY '2';      /* MAXSYMBOLS IN TABLE
LESS_THAN   LITERALLY '3';      /* MAXSYMBOLS IN TABLE
NOT_EQUAL   LITERALLY '4';      /* MAXSYMBOLS IN TABLE

DECLARE      SYMBOL(MAXSYM) CHARACTER, /* SYMBOL TABLE
FLAG        CHARACTER,           /* SYMBOL TABLE
DIRECTION   CHARACTER,           /* SYMBOL TABLE
PROBLEM(32)  BIT(16),          /* LOCATION WITHIN PROBLEM CONSTRAINT
PROBLOC(32)  BIT(8),           /* LOCATION WITHIN PROBLEM CONSTRAINT
TYPE(32)    CHARACTER,           /* LOCATION WITHIN PROBLEM CONSTRAINT
DATA(64)    CHARACTER,           /* LOCATION WITHIN PROBLEM CONSTRAINT
AUX_DATA(64) DATA PTR,          /* LOCATION WITHIN PROBLEM CONSTRAINT
AUX_PTR    FIXED,              /* LOCATION WITHIN PROBLEM CONSTRAINT
(SY, CONPTR, NUM_LANS, NUM_QUESTIONS) FIXED;

DECLARE      NSY LITERALLY '65';  /* LITERALLY '45';
DECLARE      VNSY LITERALLY '65';  /* LITERALLY '45';
DECLARE      INITIAL CHARACTER; /* TOKEN = C>; '+'; '-' ; '*' ; '/' ;
DECLARE      ERROR;             /* TOKEN = TN; '?' ; '!' ; 'HOR' ; 'VERT' ;
DECLARE      PLACE;              /* TOKEN = ANSWER; MODER; UNION; ARROWS; CARRIES;
DECLARE      EQUAL;              /* TOKEN = NUMBER; RANGE; POSITION; CIRCLE; PLANE;
DECLARE      ANGLE;              /* TOKEN = HORIZONTAL; VERTICAL; CAVERAGE;
DECLARE      MANGLES;            /* TOKEN = MEDIAN; POLYGON; COMPLEMENT;
DECLARE      DISJOINT;            /* TOKEN = POLYCONS; IDENTIFIERS; CONSTRUCTION;
DECLARE      INTERSECTION;      /* TOKEN = CINTERSECT; CONSTRUCTION;
DECLARE      TRIGONOMETRY;       /* TOKEN = CTRIGONOMETRY; AREA OF REGIONS;

```



```

DECLARE (CHARTYPE, TX) (255) BIT(8);
DECLARE (CONTROL, NOT LETTER_OR_DIGIT) (255) BIT(1);

/* ALPHABET CONSISTS OF THE SYMBOLS CONSIDERED ALPHABETIC IN BUILDING
IDENTIFIERS */
DECLARE ALPHABET CHARACTER INITIAL ('ABCDEFGHIJKLMNOPQRSTUVWXYZ-$@#');

/* BUFFER HOLDS THE LATEST CARD IMAGE; THE INPUT TEXT
NOT INCLUDING THE PORTIONS DELETED BY THE SCANNER); STORE THE POINTER TO THE END OF TEXT,
TEXT-LIMIT IS A CONVENIENT PLACE TO STORE THE SOURCE CARD READ,
CARD-COUNT IS INCREMENTED BY ONE FOR EVERY SOURCE CARD READ,
ERROR-COUNT TABULATES THE ERRORS AS THEY ARE DETECTED,
SEVERE-ERRORS TABULATES THOSE ERRORS OF FATAL SIGNIFICANCE.
*/
DECLARE (BUFFER, TEXT) CHARACTER,
        (TEXT_LIMIT, CARD_COUNT), SEVERE_ERRORS, PREVIOUS_ERROR) FIXED
        (10, 0);

/* NUMBER-VALUE CONTAINS THE NUMERIC VALUE OF THE LAST CONSTANT SCANNED,
DECLARE NUMBER-VALUE FIXED;
*/
/* EACH OF THE FOLLOWING CONTAINS THE INDEX INTO V() OF THE CORRESPONDING
SYMBOL WE ASK: IF TOKEN = IDENT ETC., STRING, LETTER) FIXED ;
DECLARE (IDENT, NUMBER, DIVIDE, Eofile, STOPIT, LETTER) FIXED;

/* STOPIT() IS A TABLE OF SYMBOLS WHICH ARE ALLOWED TO TERMINATE THE ERROR
FLUSH PROCESS. IN GENERAL THEY ARE SYMBOLS OF SUFFICIENT SYNTACTIC
HIERARCHY THAT WE EXPECT TO AVOID ATEMPTING TO START CHECKING AGAIN
RIGHT INTO ANOTHER ERROR PRODUCING SITUATION. THE TOKEN STACK IS ALSO
FLUSHED DOWN TO SOMETHING ACCEPTABLE STOPIT() SYMBOL. A GENTLE
FAILSOFT IS A BIT WHICH ALLOWS THE COMPILER ONE ATTEMPT AT A GENTLE
RECOVERY. THEN IT TAKES A STRONG HAND. WHEN THERE IS REAL TROUBLE
COMPILING IS SET TO FALSE, THEREBY TERMINATING THE COMPILATION.
*/
DECLARE STOPIT(100) BIT(1), (FAILSOFT, COMPILING) BIT(1);

DECLARE S CHARACTER; /* A TEMPORARY USED VARIOUS PLACES */

/* THE ENTRIES IN PRMASK() ARE USED TO SELECT OUT PORTIONS OF CODED
PRODUCTIONS AND THE STACK TOP FOR COMPARISON IN THE ANALYSIS ALGORITHM */
DECLARE PRMASK(5) FIXED INITIAL (0, 0, 0, 0, 0);

/* THE PROPER SUBSTRING OF POINTER IS USED TO PLACE AN UNDER THE POINT
OF DETECTION OF AN ERROR DURING CHECKING. IT MARKS THE LAST CHARACTER
SCANNED. */

```



```

DO; /* THE MARGIN CONTROL FROM DOLLAR | */
      I = LENGTH(BUFFER) - MARGIN_CHOP;
      REST = SUBSTR(BUFFER, I);
      BUFFER = SUBSTR(BUFFER, 0, I);
END;
ELSE REST = ' ';
TEXT = BUFFER;
TEXT_LIMIT = LENGTH(TEXT) - 1;
IF CONTROL(BYTE('M')) THEN OUTPUT = BUFFER;
ELSE IF CONTROL(BYTE('L')) THEN OUTPUT = '';
ELSE IF OUTPUT = I_FORMAT(CARD_COUNT, 4) || ' ' || BUFFER || ' ' || REST;
      CP = 0;
END GET_CARD;

/* THE SCANNER PROCEDURES */

```

```

CHAR:
PROCEDURE:
/* USED FOR STRINGS TO AVOID CARD BOUNDARY PROBLEMS */
CP = CP + 1;
IF CP <= TEXT_LIMIT THEN RETURN;
CALL GET_CARD;
END CHAR;

SCAN:
PROCEDURE:
DECLARE (S1$ S2) FIXED;
DECLARE LISTING CHARACTER INITIAL(' STRING TOO LONG '),
      STRDELIM CHARACTER
      LOOP BIT(S);
CALL COUNT(3) = CALLCOUNT(3) + 1;
FAILSOFT = TRUE;
RCD = ' ';
NUMBER_VALUE = 0;
SCAN1:
DO FOREVER;
  IF CP > TEXT_LIMIT THEN CALL GET_CARD;
  ELSE
    DO; /* DISCARD LAST SCANNED VALUE */
      TEXT_LIMIT = TEXT_LIMIT - CP;
      TEXT = SUBSTR(TEXT, CP);
      CP = C;
    END;
    /* BRANCH ON NEXT CHARACTER IN TEXT
    DO CASE CHARTYPE(BYTE(TEXT));
      CASE 0 */ /* */

```



```

/* ILLEGAL CHARACTERS FALL HERE: */ SUBSTR(TEXT, 0, 1));
/* CASE 1 */
DO; BLANK /*/
CP = 1;
DO WHILE BYTE(TEXT, CP) = BYTE(' ') & CP <= TEXT_LIMIT;
CP = CP + 1;
END;
CP = CP - 1;
END;

/* CASE 2 */
DO FOREVER/* A LETTER: IDENTIFIERS AND RESERVED WORDS */;
TOKEN = LETTER;
DO CP = CP + 1 TO TEXT_LIMIT;
IF NOT LETTER OR DIGIT(BYTE(TEXT, CP)) THEN
DO; /* END OF IDENTIFIER */
IF CP > LENGTH(BCD) /* SUBSTR(TEXT, 0, CP); */
S1 = LENGTH(BCD);
IF S1 <= RESERVED_LIMIT THEN
/* CHECK FOR RESERVED WORDS */
DO I = V_INDEX(S1-1) TO V_INDEX(S1) - 1;
IF BCD = V(I) THEN
DO; TOKEN = I;
RETURN;
END;
END;
/* RESERVED WORDS EXIT HIGHER: THEREFORE <IDENTIFIER> */
TOKEN = IDENT;
RETURN;
END;
/* END OF CARD */
BCD = BCD || TEXT;
CALL GET_CARD;
CP = -1;
END;

/* CASE 3 */
DO; TOKEN /* NUMBER */ =

```



```

DO FOREVER; CP TO TEXT LIMIT;
  S1 = BYTE(TEXT, CP);
  IF S1 < "FO" THEN DO; PROBLEM(CONPTR) = PROBLEM(CONPTR) || NUMBER_VALUE;
    RETURN;
  END;
  NUMBER_VALUE = 10*NUMBER_VALUE + S1 - "FO";
END;
CALL GET_CARD;
END;

/* CASE 4 */
DO; /* A : MAY BE DIVIDE OR START OF COMMENT */
  CALL CHAR;
  IF BYTE(TEXT, CP) = BYTE('**') THEN
    DO;
      TOKEN = DIVIDE;
      PROBLEM(CONPTR) = PROBLEM(CONPTR) || '**';
      RETURN;
    END;
    /* WE HAVE A COMMENT */
    S1, S2 = BYTE('**');
    DO WHILE S1 = BYTE('**') | S2 = BYTE('**');
      IF S1 = BYTE('$') THEN
        DO; /* A CONTROL CHARACTER */
          CONTROL(S2) = ? CONTROL(S2);
          IF S2 = BYTE('T') THEN CALL TRACE;
          ELSE IF S2 = BYTE('U') THEN CALL UNTRACE;
          ELSE IF S2 = BYTE('I') THEN
            IF CONTROL(S2) THEN
              MARGIN_CROP = TEXT_LIMIT - CP + 1;
            ELSE MARGIN_CROP = 0;
          END;
          S1 = S2;
          CALL CHAR;
          S2 = BYTE(TEXT, CP);
        END;
      /* CASE 5 */
      DO; TOKEN = TX(BYTE(TEXT, 0, 1));
      IF SUBSTR(TEXT, 0, 1) = '.', THEN DO;

```


INITIALIZATION:

```

--EJECT PAGE;
CALL PRINTER_DATE_AND_TIME ('SYNTAX CHECK -- NAVAL POSTGRADUATE SCHOOL --');
TEACHERS_ROLES_VERSIION_OF_DATE, DATE_OF_GENERATION, TIME_OF_GENERATION);
DOUBLE_SPACES_DATE_AND_TIME ('TODAY IS ', DATE, TIME);
DO I = 1 TO NT;
  S = V(I);
  IF S = '<NUMBER>' THEN NUMBER = I; ELSE
  IF S = '<IDENTIFIER>' THEN IDENT = I; ELSE
  IF S = '<STRING>' THEN STRING = I; ELSE
  IF S = '<LETTER>' THEN LETTER = I; ELSE
  IF S = '/' THEN DIVIDE = I; ELSE
  IF S = '-' THEN EOFILE = I; ELSE
  END;
  IF IDENT = NT THEN RESERVED_LIMIT = LENGTH(V(NT));
  ELSE RESERVED_LIMIT = EOF;
  V(EOFILE) = EOF;
  STOP_IT(EOFILE) = TRUE;
  CHAR_TYPE(BYTE(' ')) = 1;
  DO I = 0 TO 255;
    NOT LETTER_OR_DIGIT(I) = TRUE;
  END;
  DO I = 0 TO LENGTH(ALPHABET) - 1;
    TX(J) = I;
    NOT LETTER_OR_DIGIT(J) = FALSE;
    CHAR_TYPE(J) = -2;
  END;
  DO I = 0 TO 9;
    J = BYTE('0123456789'); I;
    NOT LETTER_OR_DIGIT(J) = FALSE;
    CHAR_TYPE(J) = 3;
  END;
  DO I = V_INDEX(0) TO V_INDEX(1) - 1;
    J = BYTF(V(I));
    TX(J) = I;
    CHAR_TYPE(J) = 5;
  END;
  CHAR_TYPE(BYTE('/')) = 4;
  /* FIRST SET UP GLOBAL VARIABLES
  CP = 0; TEXT_LIMIT = -1;
  TEXT = '';
  CONTROL(BYTE('L')) = TRUE;
  CONPIR, SY, NUM_ANS, NUM_QUESTS = 0;

```



```

CALL SCAN;
/* INITIALIZE THE PARSE STACK */ SP = EOFILE;
END INITIALIZATION;

LOOKUP: PROCEDURE(C);
DECLARE C CHARACTER, I FIXED;
DO I = 1 TO SY;
  IF SYMBOL(I) = C THEN RETURN I;
END;
RETURN 0;
END LOOKUP;

ENTER: PROCEDURE(C);
DECLARE C CHARACTER;
SY = SY + 1;
IF SY > MAXSYM THEN DO;
  CALL ERROR('SYMBOL TABLE OVERFLOW ',2);
  CALL EXIT;
END;
SYMBOL(SY) = C;
RETURN SY;
END ENTER;

TRACER: PROCEDURE(C) FIXED;
DECLARE C FIXED, L CHARACTER;
L = ' ';
DO I1 = MP TO SP;
  L = L || V(PARSE_STACK(I1)) || ' ';
END;
OUTPUT = ' (' || C || ' )' || L;
END TRACER;

FIND: PROCEDURE(C,L);
DECLARE C CHARACTER, (L,I,J,K) FIXED;
DO I3 = 1 TO SY;
  S = SYMBOL(I3);
  J = LENGTH(S);
  DO I4 = 0 TO J-L;
    IF SUBSTR(S,I4,L) = C THEN RETURN;
  END;
END;
I3 = 0;
RETURN;
END FIND;

FINDI: PROCEDURE(C1,C2);
DECLARE (C1,C2) CHARACTER;

```



```

DECLARE (OUT1, OUT2) CHARACTER;
OUT1 = C1 | A- NUMBER(0-1);
OUT2 = C2 | A- NUMBER(0-1);
AUX_PTR = AUX_PTR + 1;
AUX_DATA(AUX_PTR) = OUT1 || OUT2;
END_CODE1;

CODE2: PROCEDURE(C1, C2);
DECLARE (C1, C2) CHARACTER;
DECLARE (OUT1, OUT2) CHARACTER;
OUT1 = C1 | A- NUMBER(0->1);
OUT2 = C2 | A- NUMBER(0->1);
AUX_PTR = AUX_PTR + 1;
AUX_DATA(AUX_PTR) = OUT1 || OUT2;
END_CODE2;

CODE3: PROCEDURE(C1, C2);
DECLARE (C1, C2) CHARACTER;
DECLARE (OUT1, OUT2) CHARACTER;
OUT1 = C1 | A- NUMBER(0->q);
OUT2 = C2 | A- NUMBER(0->q);
AUX_PTR = AUX_PTR + 1;
AUX_DATA(AUX_PTR) = OUT1 || OUT2;
END_CODE3;

CODE4: PROCEDURE(C1, C2, C3);
DECLARE (C1, C2, C3) CHARACTER;
DECLARE (OUT1, OUT2) CHARACTER;
OUT1 = C1 | A- NUMBER(0->1);
OUT2 = C2 | A- NUMBER(0->1);
AUX_PTR = AUX_PTR + 1;
AUX_DATA(AUX_PTR) = OUT1 || OUT2;
END_CODE4;

RESOLVE: PROCEDURE;
DECLARE (TYPE_EMPROB, PROB_TEMP, OUTPUT1) CHARACTER, TEMPLOC BIT(16),
DO I = C7 TO 2;
TYPE_CNT(I) = 0;
END;
IF CONPTR = 1 THEN GO TO INSERT_CODE;
IF CONPTR > 2 THEN DO J = 2 TO CONPTR - 1;
DO I = J+1 TO CONPTR;
IF TYPE(I) > TYPE(J) THEN DO;
TEMPTYPE = TYPE(I);
TEMPLOC = PROBLEM(J);
TYPE(J) = TYPE(I);
PROBLEM(J) = PROBLEM(I);

```



```

TYPE(I) = TEMP_TYPE;
PROBLEM(I) = TEMP_PROB;
END;
DO I = 2 TO CONPTR;
DO J = 0 TO L-1;
IF BYTE(PROBLEM(I),J) = BYTE('?') THEN DO:
  CALL ERROR('QUESTION MARK APPEARS IN A CONSTRAINT EQUATION',1);
  RETURN;
END;
IF BYTE(PROBLEM(I),J) = BYTE('=') THEN DO;
  PROB_LOC(I) = SHL(J,8) | EQUALS;
  GO TO QUIT;
END;
ELSE IF BYTE(PROBLEM(I),J) = BYTE('<') THEN DO;
  IF BYTE(PROBLEM(I),J+1) = BYTE('=') THEN DO;
    PROB_LOC(I) = SHL(J,8) | LESS_EQUAL;
    GO TO QUIT;
  END;
  ELSE DO;
    PROB_LOC(I) = SHL(J,8) | LESS_THAN;
    GO TO QUIT;
  END;
END;
ELSE IF BYTE(PROBLEM(I),J) = BYTE('>') THEN DO;
  PROB_LOC(I) = SHL(L-J-2,8) | LESS_EQUAL;
  TEMP_PROB = SUBSTR(PROBLEM(I),J+2);
  PROB_TEMP = SUBSTR(PROBLEM(I),J+2);
  PROBLEM(I) = PROB_TEMP || TEMP_PROB;
  GO TO QUIT;
END;
ELSE DO;
  PROB_LOC(I) = SHL(L-J-1,8) | LESS_THAN;
  TEMP_PROB = SUBSTR(PROBLEM(I),J+1);
  PROBLEM(I) = PROB_TEMP || TEMP_PROB;
  GO TO QUIT;
END;
ELSE IF J <= L-2 THEN DO;
  PROB_LOC(I) = SHL(J,8) | NOT_EQUAL;
  GO TO QUIT;
END;

```



```

ELSE IF SUBSTR(PROBLEM(I),J,2) = 'LESS' THEN DO;
  PROBLOC = SHL(L-LOC(I),0,J);_EQUAL;
  PROBTEMP = SUBSTR(PROBLEM(I),J+2);
  PROBEM(I) = PROBTEMP || <= || TEMPB;
  GO TO QUIT;
END;
ELSE IF SUBSTR(PROBLEM(I),J,2) = 'GREATER' THEN DO;
  PROBLOC = SHL(PROBLEM(I),0,J);_EQUAL;
  PROBTEMP = SUBSTR(PROBLEM(I),J+2);
  PROBEM(I) = PROBTEMP || <= || PROBTEMP;
  GO TO QUIT;
END;
END;
QUIT: IF TYPE(I) = 0 THEN TYPE_CNT(0) = TYPE_CNT(0) + 1; ELSE
  IF TYPE(I) = 1 THEN TYPE_CNT(1) = TYPE_CNT(1) + 1; ELSE
  IF TYPE(I) = 2 THEN TYPE_CNT(2) = TYPE_CNT(2) + 1; ELSE
  IF TYPE(I) = 3 THEN TYPE_CNT(3) = TYPE_CNT(3) + 1;
END;
I1 = 0 TO 3:
I2 = TYPE_CNT(K) + I1 - 1;
IF I2 > I THEN DO I2 = I1 TO I2 - 1;
  IF (PROB_LOC(J) & "FF") > (PROB_LOC(I) & "FF") THEN DO;
    TEMPLOC = PROBLEM(J);
    TEMPLOC = PROBLEM(J);
    TEMPLOC = PROBLEM(J);
    PROBLEM(J) = PROBLEM(I);
    PROBLEM(J) = TYPE(I);
    PROBLEM(I) = TEMPLOC;
    TYPE(I) = TEMPTYPE;
  END;
  I1 = I2 + 1;
END;
END;
INSERT CODE:DATA_PTR = DATA_PTR + 1;
DATA(DATA_PTR) = PROBLEM(I);
DO I = 2 TO CONPTR;
  IF TYPE(I) = 0 THEN DO;
    IF (PROB_LOC(I) & "FF") = 1 THEN DO;

```



```

TEMPROB = SUBSTR(PROBLEM(1),0,2);
IF I1 = 0 THEN CALL ÉNTER(TEMPROB);
CALL CODE1(TEMPROB, SUBSTR(PROBLEM(1),SHR(Prob_Loc(1),8)+1));
END;

ELSE IF (PROB_Loc(1) & "FF") = 2 THEN DO;
  TEMPROB = SUBSTR(Prob(1),0,2);
  IF BYTE(TEMPROB,0) > "F0" THEN DO;
    TEMPROB = SUBSTR(Prob(1),0,2);
    PROB_TEMP = SUBSTR(Prob(1),0,2);
    SHR(Prob_Loc(1),8);
    CALL_CODE3(Prob_TEMP);
    CALL ENTER(Prob_TEMP);
  END;
  ELSE DO;
    I1 = LOOKUP(TEMPROB);
    IF I1 = 0 THEN CALL ENTER(TEMPROB);
    I1 = C;
    DO J = SHR(Prob_Loc(1),8)+1 TO LENGTH(Prob(1))-1;
      I1 = I1*10 + BYTE(SUBSTR(Prob(1),J,1)) - "F0";
    END;
    Prob_TEMP = I1 - 1;
    CALL_CODE2(TEMPROB, Prob_TEMP);
  END;
END;

ELSE IF (PROB_Loc(1) & "FF") = 3 THEN DO;
  TEMPROB = SUBSTR(Prob(1),0,2);
  IF BYTE(TEMPROB,0) > "F0" THEN DO;
    TEMPROB = SUBSTR(Prob(1),0,2);
    PROB_TEMP = SUBSTR(Prob(1),0,2);
    SHR(Prob_Loc(1),8);
    CALL_CODE3(Prob_TEMP);
    CALL ENTER(Prob_TEMP);
  END;
  ELSE DO;
    I1 = LOOKUP(TEMPROB);
    IF I1 = 0 THEN DO;
      CALL_CODE2(TEMPROB);
      CALL ENTER(TEMPROB);
    END;
  END;
END;

ELSE IF (PROB_Loc(1) & "FF") = 4 THEN DO;
  TEMPROB = SUBSTR(Prob(1),0,2);
  I1 = LOOKUP(TEMPROB);
  IF I1 = 0 THEN DO;
    CALL ENTER(TEMPROB);
  END;
END;

```



```

I2 = C; SHR(PROB_LOC(I),8)+2 TO LENGTH(PROBLEM(I),J,1) - "FO";
I2 = I2*1C + BYTE(SUBSTR(PROBLEM(I),J,1)) - "FO";
END;
PROB_TEMP = I2 - 1;
OUTPUTI = I2 + 1;
CALL CODE4(TEMPROB, PROB_TEMP, OUTPUTI);
END;
ELSE CALL ERROR('IDENTIFIER HAS BEEN ENTERED IN THE SYMBOL TABLE');
END;

ELSE IF TYPE(I) = 1 THEN DO;
  IF (PROB_LOC(I) & "FF") = 1 THEN DO;
    I2 = LOOKUP(TEMPROB);
    IF I1 = 0 THEN DO;
      CALL ENTER(TEMPROB);
      CALL CODE1(TEMPROB,SUBSTR(PROBLEM(I),SHR(PROB_LOC(I),8)+1));
    END;
    ELSE DO;
      PROB_TEMP = SUBSTR(PROBLEM(I),SHR(PROB_LOC(I),8)+1);
      I2 = LOOKUP(PROB_TEMP);
      IF I2 = 0 THEN DO;
        CALL ENTER(PROB_TEMP);
        CALL CODE1(PROB_TEMP,TEMPROB);
      END;
      ELSE CALL ERROR('BOTH IDENTIFIERS HAVE BEEN ENTERED IN THE SYMBOL TABLE',0);
    END;
  END;
  ELSE IF (PROB_LOC(I) & "FF") = 2 THEN DO;
    I2 = LOOKUP(TEMPROB);
    IF I1 = 0 THEN DO;
      CALL ENTER(TEMPROB);
      PROB_TEMP = SUBSTR(PROBLEM(I),SHR(PROB_LOC(I),8)+1)||'-1';
      CALL CODE2(TEMPROB, PROB_TEMP);
    END;
    ELSE DO;
      PROB_TEMP = SUBSTR(PROBLEM(I),SHR(PROB_LOC(I),8)+1);
      I2 = LOOKUP(PROB_TEMP);
      IF I2 = 0 THEN DO;
        CALL ENTER(PROB_TEMP);
        TEMPORB = TEMPORB || I1;
        CALL CODE2(TEMPORB, PROB_TEMP);
      END;
    END;
  END;
END;

```



```

END; CALL ERROR('BOTH IDENTIFIERS HAVE BEEN ENTERED IN THE ' ||

ELSE, SYMBOL_TABLE); END;
END;

ELSE IF (PROB_LOC(I) & "FF") = 3 THEN DO;
  PROB = SURSTR(PROBLEM(I),G,2);
  I1 = LOOKUP(TEMPPROB);
  IF I1 = 0 THEN DO;
    CALL ENTER(TEMPPROB);
    CALL CODE2(TEMPFOR, SUBSTR(PROBLEM(I), SHR(PROB_LOC(I),8)+2));
  END; DO;
    PROB_TEMP = SUBSTR(PROBLEM(I), SHR(PROB_LOC(I),8)+2);
    I2 = LOOKUP(PROB_TEMP);
    IF I2 = 0 THEN DO;
      CALL ENTER(PROB_TEMP);
      CALL CODE2(TEMPFOR, TEMPORB);
    END; CALL ERROR('BOTH IDENTIFIERS HAVE BEEN ENTERED IN THE ' ||
      ELSE, SYMBOL_TABLE); END;
  END;

ELSE IF (PROB_LOC(I) & "FF") = 4 THEN DO;
  PROB = SUBSTR(PROBLEM(I),0,2);
  I1 = LOOKUP(TEMPPROB);
  IF I1 = 0 THEN DO;
    CALL ENTER(TEMPPROB);
    OUTPUT1 = PROB_TEMP || ' +1';
    PROB_TEMP = PROB_TEMP || ' -1';
    CALL CODE4(TEMPFOR, PROB_TEMP, OUTPUT1);
  END; DO;
    I1 = LOOKUP(PROB_TEMP);
    IF I1 = 0 THEN DO;
      CALL ENTER(PROB_TEMP);
      OUTPUT1 = TEMPORB || ' +1';
      TEMPORB = TEMPORB || ' -1';
      CALL CODE4(TEMPFOR, PROB_TEMP, TEMPORB, OUTPUT1);
    END; CALL ERROR('BOTH IDENTIFIERS HAVE BEEN ENTERED IN THE ' ||
      ELSE, SYMBOL_TABLE); END;
  END;
END;

```



```

ELSE IF TYPE(I) = 2 THEN DO;
  IF (PROB_LOC(I) & "FF") = 1 THEN DO;
    TEMPORB = SUBSTR(PROBLEM(I),1,2);
    PROB_TEMP = SUBSTR(TEMPORB);
    IF I1 = LOOKUP(TEMPORB);
    IF I1 = C THEN DO;
      CALL ENTER(TEMPORB);
      OUTPUT1 = SUBSTR(TEMPORB,PROBLEM(I),8)+1)|| PROB_TEMP;
      CALL CODE3(TEMPORB,OUTPUT1);
    END;
    ELSE DO;
      I1 = LOOKUP(TEMPORB);
      IF I1 = C THEN DO;
        CALL ENTER(TEMPORB);
        OUTPUT1 = SUBSTR(TEMPORB,PROBLEM(I),8)+1)|| PROB_TEMP;
        CALL CODE3(TEMPORB,OUTPUT1);
      END;
      ELSE CALL FERROR("BOTH IDENTIFIERS HAVE BEEN ENTERED IN THE • ||");
    END;
  END;
  ELSE IF (PROB_LOC(I) & "FF") = 2 THEN DO;
    TEMPORB = SUBSTR(PROBLEM(I),1,2);
    IF BYTE(TEMPORB,2) > "F0" THEN DO;
      PROB_TEMP = SUBSTR(PROBLEM(I),1,2);
      PROB_TEMP = SUBSTR(TEMPORB,PROBLEM(I),8)+1;
      OUTPUT1 = SUBSTR(TEMPORB,PROBLEM(I),8)+4,2);
      I2 = 0;
      DO J = 0 TO LENGTH(TEMPORB)-1;
        I2 = I2 + BYTE(SUBSTR(TEMPORB,J,1)) - "F0";
      END;
      I2 = I2 + 1;
      I1 = LOOKUP(TEMPORB);
      IF I1 = C THEN DO;
        TEMPORB = I2||"";
        CALL CODE3(TEMPORB,TEMPORB);
      END;
      ELSE DO;
        I1 = LOOKUP(OUTPUT1);
        IF I1 = C THEN DO;
          CALL ENTER(I2||"");
          TEMPORB = I2||"";
          CALL CODE3(TEMPORB,TEMPORB);
        END;
      END;
    END;
  END;

```



```

CALL CODE3(OUTPUT1,TEMPROB);
END;
ELSE CALL ERROR('BOTH IDENTIFIERS HAVE BEEN ENTERED IN THE ' ||
' SYMBOL TABLE',0);
END;
ELSE DO;
PROB_TEMP = SUBSTR(PROBLEM(1),3,2);
I1 = LOOKUP(TEMPROB);
IF I1 = 0 THEN DO;
CALL CNTFP(TEMPROB);
OUTPUT1 = SUBSTR(PROBLEM(1),SHR(PROB_LOC(1),8)+1) || '-' || |
PROB_TEMP;
CALL CODE2(TEMPROB,OUTPUT1);
ELSE DO;
I1 = LOOKUP(TEMPROB);
IF I1 = 0 THEN DO;
CALL CENTER(TEMPROB);
OUTPUT1 = SUBSTR(PROBLEM(1),SHR(PROB_LOC(1),8)+1) || '-' || |
TEMPROB;
CALL CODE2(TEMPROB,OUTPUT1);
END;
ELSE CALL ERROR('BOTH IDENTIFIERS HAVE BEEN ENTERED IN THE ' ||
' SYMBOL TABLE',0);
END;
END;
ELSE IF (PROB_LOC(1) & "FF") = 3 THEN DO;
TEMPROB = SUBSTR(PROBLEM(1),2);
IF BYTER(TEMPROB,0) > "FO" THEN DO;
TEMPROB = SUBSTR(PROBLEM(1),2,SHR(PROB_LOC(1),8));
PROB_TEMP = SUBSTR(PROBLEM(1),SHR(PROB_LOC(1),8)+2,2);
OUTPUT1 = SUBSTR(TEMPROB);
I1 = LOOKUP(TEMPROB);
IF I1 = 0 THEN DO;
CALL CENTER(TEMPROB);
TEMPROB = TEMPORB || '-' || OUTPUT1;
CALL CODE3(OUTPUT1,TEMPROB);
END;
ELSE DO;
I1 = LOOKUP(OUTPUT1);
IF I1 = 0 THEN DO;
CALL CENTER(OUTPUT1);
TEMPROB = EXPROB || '-' || PROB_TEMP;
CALL CODE3(OUTPUT1,TEMPROB);
END;

```



```

ELSE CALL ERROR('BOTH IDENTIFIERS HAVE BEEN ENTERED IN THE '||

END;
ELSE DO;
  PROB_TEMP = SUBSTR(PROBLEM(I),3,2);
  IF I1 = 0 THEN DO;
    CALL ENTER(TMPROB);
    OUTPUT1 = SUBSTR(PROBLEM(I),SHR(PROB_LOC(I),8)+2) || ' - ' ||

    PROB_TEMP;
    CALL CODE2(TMPROB,OUTPUT1);

  END;
  ELSE DO;
    I1 = LOOKUP(PROB_TEMP);
    IF I1 = OTHER THEN DO;
      CALL ENTER(PROB_TEMP);
      OUTPUT1 = SUBSTR(PROBLEM(I),SHR(PROB_LOC(I),8)+2) || ' - ' ||

      TEMP_PROB;
      CALL CODE2(PROB_TEMP,TEMP_PROB);

    END;
    ELSE CALL ERROR('BOTH IDENTIFIERS HAVE BEEN ENTERED IN THE '||

    SYMBOL_TABLE,O);
  END;
  END;
END;
END;
END;
DO I = 1 TO SY;
  L = LENGTH(SYMBOL(I));
  IF L <= 2 THEN GO TO FINIS;
  DO J = 0 TO L-2 BY 2;
    S = SUBSTR(SYMBOL(I),J,2);
    I1 = LOOKUP(S);
    IF I1 = 0 THEN DO;
      CALL ENTER(S);
      DATA_PTR = DATA_PTR || S || I = A_NUMBER(0->9);

    END;
    END;
  END;
  FINIS: DO I = 1 TO AUX_PTR;
    DATA_PTR = DATA_PTR + 1;
    DATA_PTR = AUX_DATA(I);
  END;
  DO I = 1 TO DATA_PTR;
    OUTPUT = DATA(I);
    OUTPUT(2) = DATA(I);
  END;

```



```

END;
OUTPUT(2) = DIRECTION !:,:;
END RESOLVE;

DUMPIT: PROCEDURE; /* DUMP OUT THE STATISTICS COLLECTED DURING THIS RUN */
/* PUT OUT THE ENTRY COUNT FOR IMPORTANT PROCEDURES */
OUTPUT = !STACKING DECISIONS= ! || CALLCOUNT(1);
OUTPUT = !SCAN ! || CALLCOUNT(2);
OUTPUT = !FREE STRING AREA = ! || FREELIMIT = FREEBASE;
END DUMPIT;

STACK_DUMP: PROCEDURE;
DECLARE LINE CHARACTER; TO THIS POINT IS: '';
LINE = 'PARTIAL PARSE';
DO I = 2 TO SP;
IF LENGTH(LINE) > 105 THEN
DO: OUTPUT = LINE;
LINE = X4;
END;
LINE = LINE || X1 || V(PARSE_STACK(I));
OUTPUT = LINE;
END STACK_DUMP;
/* */

SYNTHEZIZE: PROCEDURE(PRODUCTION_NUMBER);
DECLARE (PRODUCTION_NUMBER, CONCNT) FIXED;
DECLARE (ANS, QUES) BYTE(1), CHAR CHARACTER;
IF CONTROL(BYTE(P)) THEN CALL TRACER(PRODUCTION_NUMBER);
DO CASE PRODUCTION_NUMBER;
/* <TEACHERS STATEMENT> ::= <TEACHERS DEFINITION> */
IF MP = 2 THEN /* WE DIDN'T GET HERE LEGITIMATELY */
DO; CALL ERROR ('END; AT INVALID POINT', 1);

```



```

CALL STACK_DUMP;
END;
OUTPUT(2) = 'EOF EOF EOF';
COMPILING = FALSE;
END;

/* <TEACHERS DEFINITION> ::= <PROBLEM DEFINITION> */

SAME: CALL RESOLVE;
DO I = 1 TO DATA_PTR;
  AUX_DATA(I) = 0;
  DATA(I) = 0;
END;
DO I = 1 TO CONPTR;
  PROBLEM(I) = 0;
  PROB_LOC(I), TYPE(I) = 0;
END;
DO I = 0 TO SY;
  SYMBOL(I) = 0;
END;
SY, DATA_PTR, AUX_PTR = 0;
CONPTR, CONCNT = 1;
FLAG = TRUE;
END;

/* <TEACHERS DEFINITION> ::= <TEACHERS DEFINITION> <PROBLEM DEFINITION> */
/* GO TO SAME; */

/* <TEACHERS DEFINITION> ::= <FUNCTION DEFINITION> */
/* ; */

/* <TEACHERS DEFINITION> ::= <TEACHERS DEFINITION> <FUNCTION DEFINITION> */
/* ; */

/* <TEACHERS DEFINITION> ::= <DEFINITION DEFINITION> */
/* ; */

/* <TEACHERS DEFINITION> ::= <TEACHERS DEFINITION> <DEFINITION DEFINITION> */
/* ; */

/* <PROBLEM DEFINITION> ::= <SET OPERATIONS> */
/* ; */

/* <PROBLEM DEFINITION> ::= <ARITHMETIC OPERATIONS> <PROBLEM CONSTRUCTION> */
/* <PROBLEM CONSTRAINTS> */
/* ; */

/* <PROBLEM DEFINITION> ::= <ARITHMETIC OPERATIONS> <PROBLEM CONSTRUCTION> */
/* APPROVE: DIRECTION = VAR(MAPP1); */

```



```

/* <PROBLEM DEFINITION> ::= <ARITHMETIC OPERATIONS> <PROBLEM CONSTRUCTION>
GO TO ABOVE;
/* <PROBLEM DEFINITION> ::= <GEOMETRY> */
/* <PROBLEM DEFINITION> ::= <STATISTICS AND PROBABILITY> */
/* <PROBLEM DEFINITION> ::= <TRIGONOMETRY> */
/* <ARITHMETIC OPERATIONS> ::= <EXPRESSION> <RELATION> <EXPRESSION> */
/* DO; ANS, QUES = "0";
DO i = 1 TO LENGTH(PROBLEM(1))-1;
IF SUBSTR(PROBLEM(1),i,1) = "?" THEN QUES = "1";
IF i <= LENGTH(PROBLEM(1))-6 THEN IF SUBSTR(PROBLEM(1),i,6) = "ANSWER"
THEN ANS = "1";
END;
IF NUM_ANS > 1, THEN DO;
CALC_ERROR();
MORE THAN ONE ANSWER IN THE SAME EQUATION . ,1);
RETURN;
END;
IF NUM_QUESTS > 1, THEN DO;
CALC_ERROR();
MORE THAN ONE ? IN THE SAME EQUATION . ,1);
RETURN;
END;
IF ANS & QUES THEN DO;
CALC_ERROR();
ANS AND QUESTION MARK ARE IN SAME EQUATION . ,1);
RETURN;
END;
IF ANS & QUES, THEN DO;
CALC_ERROR();
NEITHER ANSWER NOR QUESTION MARK ARE IN THE EQUATION . ,1);
RETURN;
END;
NUM_ANS, NUM_QUESTS = 0;
END;
/* <EXPRESSION> ::= <TERM> */
/* <EXPRESSION> ::= <EXPRESSION> + <TERM> */
/* <EXPRESSION> ::= <EXPRESSION> - <TERM> */

```



```

;   <EXPRESSION> ::= + <TERM>      */
;   <EXPRESSION> ::= - <TERM>      */
;   <TERM> ::= <PRIMARY>      */
;   <TERM> ::= <TERM> * <PRIMARY>      */
;   <TERM> ::= <TERM> / <PRIMARY>      */
;   <PRIMARY> ::= <NUMBER>      */
;   <PRIMARY> ::= <IDENTIFIER>      */
; DO; I1 = LOOKUP(VAR(MP));
; IF I1 = 0 THEN ENTER(VAR(MP));
; END;
; <PRIMARY> ::= ( <ARITHMETIC OPERATIONS> )      */
; <PRIMARY> ::= ANSWER      */
; NUM_ANS = NUM_ANS + 1;
; <RELATION> ::= =      */
; <RELATION> ::= <      */
; <RELATION> ::= >      */
; <RELATION> ::= =      */
; <RELATION> ::= =      */
; <RELATION> ::= <      */
; <RELATION> ::= >      */

```



```

; <RELATION> ::= < = */  

/* <RELATION> ::= > = */  

/* <RELATION> ::= ? */  

/* NUM_QUESTS = NUM_QUESTS + 1;  

/* <PROBLEM CONSTRUCTION> ::= <PROBLEM DIRECTION> CARRIES IN <IDENTIFIER>  

PLACE:  

DO; IF VAR(SP-1) = 'ONES' THEN POSITION = 1; ELSE  

IF VAR(SP-1) = 'TENS' THEN POSITION = 2; ELSE  

IF VAR(SP-1) = 'HUNDREDS' THEN POSITION = 3; ELSE  

IF VAR(SP-1) = 'THOUSANDS' THEN POSITION = 4;  

STA: I1 = SY;  

CHAR = ' ';  

DO J = 1 TO I1: /* ANSWER */  

IF SYMBOL(J) = ' ' THEN DO;  

CHAR = SUBSTR(SYMBOL(J),0,1) || POSITION;  

CALL ENTER(CHAR);  

END;  

ELSE DO;  

CALL CODE3(CHAR, SUBSTR(SYMBOL(J),0,1) || POSITION);  

GO TO CONT;  

END;  

END;  

CONT: END;  

DO; POSITION = FIXV(SP);  

GO TO STA;  

END;  

/* <PROBLEM CONSTRUCTION> ::= <PROBLEM DIRECTION> CARRIES IN POSITION <NUMBER>  

DO; POSITION = FIXV(SP);  

GO TO STA;  

END;  

/* <PROBLEM CONSTRUCTION> ::= <PROBLEM DIRECTION> BARROWS IN <IDENTIFIER>  

PLACE:  

DO; IF VAR(SP-1) = 'ONES' THEN POSITION = 1; ELSE  

IF VAR(SP-1) = 'TENS' THEN POSITION = 2; ELSE  

IF VAR(SP-1) = 'HUNDREDS' THEN POSITION = 3; ELSE  

IF VAR(SP-1) = 'THOUSANDS' THEN POSITION = 4; ELSE  

END;

```



```

/* <PROBLEM CONSTRUCTION> ::= <PROBLEM DIRECTION> BARROWS IN POSITION <NUMBER>
POSITION = FIXV(SP);
/* <PROBLEM CONSTRUCTION> ::= <PROBLEM DIRECTION> POSITION = 0; */
/* <PROBLEM DIRECTION> ::= VERT */
/* <PROBLEM DIRECTION> ::= VERTICAL */
/* VAR(MP) = VERT; */
/* <PROBLEM DIRECTION> ::= HORIZ */
/* VAR(MP) = HOR; */
/* <PROBLEM DIRECTION> ::= HOR */
/* VAR(MP) = HOR; */
/* <PROBLEM DIRECTION> ::= HORIZONTAL */
/* VAR(MP) = HOR; */
/* <PROBLEM CONSTRAINTS> ::= <PROBLEM CONSTRAINTS RIGHT> */
/* <PROBLEM CONSTRAINTS> ::= <PROBLEM CONSTRAINTS> <PROBLEM CONSTRAINTS RIGHT> */
/* <PROBLEM CONSTRAINTS> ::= <PROBLEM CONSTRAINTS> <PROBLEM CONSTRAINTS RIGHT> */
/* <PROBLEM CONSTRAINTS RIGHT> ::= <LEFT PROBLEM CONSTRAINT> <NUMBER> */
CONCNT = CONCNT + 1;
IF FIXV(MP) = 3 THEN TYPE{CONCNT} = 2; ELSE
IF FIXV(MP) = 1 THEN TYPE{CONCNT} = 0;
END;
/* <PROBLEM CONSTRAINTS RIGHT> ::= <LEFT PROBLEM CONSTRAINT> <IDENTIFIER>
DO; CONCNT = CONCNT + 1;
TYPE{CONCNT} = FIXV(MP);
I2 = LENGTH(VAR(SP));
CALL FIND(VAR(SP));
IF I2 = 0 THEN CALL ERROR(' INVALID CONSTRAINT ',1);
END;
/* <LEFT PROBLEM CONSTRAINT> ::= < MIDDLE CONSTRAINT > <IDENTIFIER> <RELATION>

```



```

*/  

DO; FIXV(MP) = 1;  

  GO TO MID;  

END;  

/* <LEFT PROBLEM CONSTRAINT> ::= , <IDENTIFIER> <RELATION> */  

DO;  

  FIXV(MP) = 1;  

  MID: I2 = LENGTH(VAR(MP1));  

  I2 = LENGTH(VAR(MP1));  

  CALL FIND(VAR(MP1),I2);  

  IF I2 = 0 THEN DO;  

    CALL ERROR('INVALID CONSTRAINTS ',1);  

  END;  

END;  

/* <MIDDLE CONSTRAINT> ::= , <IDENTIFIER> + */  

/* GO TO MID;  

/* <SET OPERATIONS> ::= <UNION> */  

/* ;  

/* <SET OPERATIONS> ::= <INTERSECTION> */  

/* ;  

/* <SET OPERATIONS> ::= <COMPLEMENT> */  

/* ;  

/* <SET OPERATIONS> ::= <DISJOINT> */  

/* ;  

/* <SET OPERATIONS> ::= <EQUAL> */  

/* ;  

/* <GEOMETRY> ::= <METRIC> */  

/* ;  

/* <GEOMETRY> ::= <NON-METRIC> */  

/* ;  

/* <STATISTICS AND PROBABILITY> ::= <MEASURE OF CENTRAL TENDENCY> */  

/* ;  

/* <METRIC> ::= <AREA OF REGIONS> */  

/* ;  

/* <NON-METRIC> ::= <LINES, POINTS AND CURVES> */  


```



```

; <NON-METRIC> ::= <PLANES> /*/
; <NON-METRIC> ::= <ANGLES> /*/
; <NON-METRIC> ::= <POLYGONS> /*/
; <NON-METRIC> ::= <CIRCLES> /*/
; <NON-METRIC> ::= <CONSTRUCTION> /*/
; <MEASURE OF CENTRAL TENDENCY> ::= <AVVERAGE> /*/
; <MEASURE OF CENTRAL TENDENCY> ::= <RANGE> /*/
; <MEASURE OF CENTRAL TENDENCY> ::= <MODE> /*/
; <MEASURE OF CENTRAL TENDENCY> ::= <MEDIAN> /*/
END;
/* SYNTHESIZE;
   SYNTACTIC PARSING FUNCTIONS
   */
RIGHT_CONFLICT:
PROCEDURE (LEFT) BIT(1);
DECLARE LEFT FIXED;
/* THIS PROCEDURE IS TRUE IF TOKEN IS A LEGAL RIGHT CONTEXT OF LEFT*/
RETURN (TOKEN & SHL(BYTE(C1(LEFT), 1), 1)) == 0;
END RIGHT_CONFLICT;

RECOVER:
PROCEDURE;
/* IF THIS IS THE SECOND SUCCESSIVE CALL TO RECOVER, DISCARD ONE SYMBOL */
IF ~FAILSOFT THEN CALL SCAN;

```



```

FAILSOFT = FALSE; /* TO FIND SOMETHING SOLID IN THE TEXT */
DO WHILE SCAN; /* TO FIND
END;
DO WHILE RIGHT CONFLICT (PARSE_STACK(SP)); /*/
DO IF SP = SP - 1; /* AND IN THE STACK */
ELSE CALL SCAN; /* BUT DON'T GO TOO FAR */
END;
CUTPUT = *RESUME: || SUBSTR(POINTER, TEXT_LIMIT-CP+MARGIN_CHOP+7); /*

STACKING:
PROCEDURE BIT(1); /* STACKING DECISION FUNCTION */
CALL COUNT(1) = CALL COUNT(1) + 1; /*/
DO FOREVER; /*UNTIL RETURN */
DO CASE; SHR(BYTE(C1(PARSE_STACK(SP)); SHR(TOKEN,2)), SHL(3-TOKEN,1))E6)E3;
DO; CASE 0 /* ILLEGAL SYMBOL PAIR */
DO; CALL ERROR("ILLEGAL SYMBOL PAIR: " || V(PARSE_STACK(SP)) || X1 || V(TOKEN));
CALL STACK_DUMP;
CALL RECOVER;
END;
/* CASE 1 */ /* STACK TOKEN */
RETURN TRUE; /* STACK TOKEN */
/* CASE 2 */ /* DON'T STACK IT YET */
RETURN FALSE;
/* CASE 3 */ /* MUST CHECK TRIPLES */
DO; J = SHL(PARSE_STACK(SP-i), 16) + SHL(PARSE_STACK(SP-i-1), 8) + TOKEN;
I = -1; K = NC1TRIPLES + 1; /*/
DO WHILE I + 1 < K;
L = SHR(I+K, 1);
IF C1TRIPLES(L) > J THEN K = L;
ELSE C1TRIPLES(L) /* IF C1TRIPLES(L) > J THEN K = L;
ELSE RETURN TRUE; /* IF C1TRIPLES(L) < J THEN K = L;
END;
RETURN FALSE;
END;
/* OF DO CASE */

```



```

PR_CK: /* CF DO FOREVER */
END STACKING;

/* DECISION PROCEDURE FOR CONTEXT CHECK OF EQUAL OR IMBEDDED RIGHT PARTS*/
DO CASE CONTEXT_CASE(PRD);
  /* CASE 0 -- NO CHECK REQUIRED */
  RETURN TRUE;
  /* CASE 1 -- RIGHT CONTEXT CHECK */
  RETURN ~RIGHT_CONFLICT(HDTB(PRD));
  /* CASE 2 -- LEFT CONTEXT CHECK */
  DO; H = HDTB(PRD); NT = PRLENGTH(PRD);
  I = PARSESTACK(SP-PRLENGTH(PRD));
  DO J = LEFT_CONTEXT(H-1) TO LEFT_INDEX(H)-1;
    IF LEFT_CONTEXT(J) = I THEN RETURN TRUE;
  END;
  RETURN FALSE;
END;
  /* CASE 3 -- CHECK TRIPLES */
  DO; H = HDTB(PRD); NT = PRLENGTH(PRD); P = TOKEN;
  I = SHL(PARSESTACK(SP-PRLENGTH(PRD)), 8) + TOKEN;
  DO J = TRIPLE_INDEX(H-1) TO TRIPLE_INDEX(H)-1;
    IF CONTEXT_TRIPLE(J) = I THEN RETURN TRUE;
  END;
  RETURN FALSE;
END;
END PR_OK;
/* OF DO CASE */
/* ANALYSIS ALGORITHM */
/* PROCEDURE: */
/* DECLARE: (I, J, PRD) FIXED;

```



```

/* PACK STACK TOP INTO ONE WORD */
DO I = SP-4 TO SP-1;
END;

DO PRD = PRINDEX(PARSE_STACK(PRD)) TO PRINDEX(PARSE_STACK(SP)) - 1;
  IF PRMASK(PRLNGTH(PRD)) THEN
    IF PROK(PRD) THEN
      DO; /* AN ALLOWED REDUCTION */
        MP = SP - PRLNGTH(PRD) + 1; MPP1 = MP + 1;
        CALL SYNTHESIZE(PRDTB(PRD));
        SP = MP;
        PARSE_STACK(SP) = HDTB(PRD);
        RETURN;
      END;
    END;
  END; /* LOOK UP HAS FAILED; ERROR CONDITION */
  CALL ERROR('NO PRODUCTION IS APPLICABLE', 1);
  CALL STACK_DUMP;
  FAILSOFT = FALSE;
  CALL RECOVER;
  END REDUCE;
END;

COMPILE LOOP:
PROCEDURE:
  COMILING = TRUE;
  FLAG = TRUE;
  CONPTR = 1;
  DO I = 1 TO 32; PROBLEM(I) = 0;
  END;
  DO WHILE COMILING; /* ONCE ARGUND FOR EACH PRODUCTION (REDUCTION)
    DO WHILE STACKING;
      SP = SP + 1;
      IF SP = STACKSIZE THEN
        DO; /* STACK OVERFLOW */
          CALL ERROR('STACK OVERFLOW *** CHECKING ***');
          RETURN; /* THUS ABORTING CHECKING */
        END;
      END;
      PARSE_STACK(SP) = TOKEN;
      VAR(SP) = BCD;
      FIXV(SP) = NUMBER VALUE;
      IF SUBSTR(BCD, 0, 3) = 'VER' | SUBSTR(BCD, 0, 3) = 'HOR' |
        IF THEN FLAG = FALSE;
        IF FLAG THEN PROBLEM(CONPTR) = PROBLEM(CONPTR) || VAR(SP);
  END;

```



```

CALL SCAN;
END;

CALL REDUCE;
END; /* OF DO WHILE COMPILEING */
END COMPILEATION_LOOP;

PRINT_SUMMARY:
DECLARE I FIXED;
CALL PRINT_DATE_AND_TIME ('END OF CHECKING ', DATE, TIME);
OUTPUT = CARD_COUNT || ' CARDS WERE CHECKED.';
IF ERROR_COUNT = 0 THEN OUTPUT = 'NO ERRORS WERE DETECTED.';
ELSE IF ERROR_COUNT > 1 THEN OUTPUT = ' ERRORS (' || SEVERE_ERRORS
|| ' SEVERE ERRORS WERE DETECTED.';
ELSE IF SEVERE_ERRORS = 1 THEN OUTPUT = 'ONE SEVERE ERROR WAS DETECTED.';
ELSE IF SEVERE_OUTPUT = 'ONE ERROR WAS DETECTED.';
IF PREVIOUS_ERROR > 0 THEN OUTPUT = 'THE LAST DETECTED ERROR WAS ON LINE ' || PREVIOUS_ERROR
PERIOD || ' PERIOD';
IF CONTROL_BYTE(.D.) THEN CALL DUMPIT;
DOUBLE SPACE;
CLOCK(3) = TIME;
DO I = 1 TO 3; /* WATCH OUT FOR MIDNIGHT */
IF CLOCK(I) < CLOCK(I-1) THEN CLOCK(I) = CLOCK(I) + 8640000;
END;
CALL PRINT_TIME ('TOTAL TIME IN CHECKER ', CLOCK(3) - CLOCK(0));
CALL PRINT_TIME ('SETUP TIME ', CLOCK(1) - CLOCK(0));
CALL PRINT_TIME ('ACTUAL CHECKING TIME ', CLOCK(2) - CLOCK(1));
CALL PRINT_TIME ('CLEAN-UP TIME AT END ', CLOCK(3) - CLOCK(2));
IF CLOCK(2) > CLOCK(1) THEN /* WATCH OUT FOR CLOCK BEING OFF */
OUTPUT = 'CHECKING RATE: ' || 6000*CARD_COUNT/(CLOCK(2)-CLOCK(1))
|| ' CARDS PER MINUTE.';

END PRINT_SUMMARY;

MAIN PROCEDURE:
PROCEDURE;
CLOCK(0) = TIME; /* KEEP TRACK OF TIME IN EXECUTION */
CALL INITIALIZATION;
CLOCK(1) = TIME;
CALL COMPILEATION_LOOP;

```



```
CLOCK(2) = TIME;
/* CLOCK(3) GETS SET IN PRINT_SUMMARY */
CALL PRINT_SUMMARY;
END MAIN_PROCEDURE;

CALL MAIN_PROCEDURE;
RETURN SEVERE_ERRORS;
EOF ECF EOF
```


APPENDIX C

Format description of language for communicating with
PROBLEM DESCRIPTION INTERPRETER.

The meta-symbols used in the description of the language
serve the following functions:

`::=` is used to indicate a definition

`|` is used to indicate alternate definitions

`< >` are used to enclose items which are elements of
the meta-language which describe the elements of
the PROBLEM DESCRIPTION INTERPRETER language

```
<interpreter> ::= <interpreter statement> ;  
  
<interpreter statement> ::= <problem statement> | <interpreter  
statement> ; <problem statement>  
| <interpreter statement> <right  
statement> | <interpreter  
statement> <direction>  
  
<right statement> ::= <left part> <a_number(>  
  
<a_number(> ::= <a_number> <digit part>  
  
<a_number> ::= A_NUMBER (<identifier> | A_NUMBER(  
    <number>  
  
<digit part> ::= ) | <minus identifier> <arrow number> ) |  
    <right part> <plus number> <arrow number> ) |  
    | <arrow number <minus identifier> ) |  
    <arrow identifier> <minus number> ) |  
    <arrow identifier> ) | <arrow number> )  
  
<arrow number> ::= -> <number>  
  
<arrow identifier> ::= -> <identifier>  
  
<right part> ::= <arrow identifier> <minus number> ,  
    <identifier>  
  
<plus number> ::= + <number>  
  
<minus number> ::= - <number>  
  
<left part> ::= <identifier =>
```



```
<identifier => ::= <identifier> =  
<problem statement> ::= <expression> <relation> <expression>  
<expression> ::= <term> | <expression> + <term> | <expression>  
          - <term>  
<term> ::= <primary> | <term> * <primary> | <term> / <primary>  
<primary> ::= <number> | <identifier> | ( <expression> ) |  
          ANSWER  
<relation> ::= = | < | > | ≠ | & | × | <= | >= | ?  
<direction> ::= HOR | VERT
```


APPENDIX D

PROBLEM DESCRIPTION INTERPRETER

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```

DECLARE NSY LITERALLY '43' INIT LITERALLY '29'; TOKEN = 0;
DECLARE V(NSY) CHARACTER INITIAL ('<ERROR>'); HOR = 'V'; VERT = 'V';
DECLARE V(1) INDEX(12) BIT(8) INITIAL ( 1, 14, 16, 17, 18, 19, 20, 21);
DECLARE V(2) INDEX(12) BIT(8) INITIAL ( 1, 14, 16, 17, 18, 19, 20, 21);

```


TX() IS A TABLE USED FOR TRANSLATING FROM ONE CHARACTER SET TO ANOTHER. CONTROL() HOLDS THE VALUE OF THE COMPILER CONTROL TOGGLE SET IN \$ CARDS. NOT LETTER OR DIGIT() IS SIMILAR TO CHARTYPE() BUT USED IN SCANNING IDENTIFIERS ONLY.

ALL ARE USED BY THE SCANNER AND CONTROL() IS SET THERE.

```
/*/
DECLARE (CHARTYPE, TX) (255) BIT(8);
  (CONTROL, NOT LETTER_OR_DIGIT) (255) BIT(1);

/* ALPHABET CONSISTS OF THE SYMBOLS CONSIDERED ALPHABETIC IN BUILDING
IDENTIFIERS */
DECLARE ALPHABET CHARACTER INITIAL ('ABCDEFGHIJKLMNOPQRSTUVWXYZ_@#');

/* BUFFER HOLDS THE LATEST CARD IMAGE.
TEXT HOLDS THE PRESENT STATE OF THE INPUT TEXT
(NOT INCLUDING THE PORTIONS DELETED BY THE SCANNER)
TEXT-LIMIT IS A CONVENIENT PLACE TO STORE THE POINTER TO THE END OF TEXT,
CARD-COUNT IS INCREMENTED BY ONE FOR EVERY SOURCE CARD READ,
ERROR-COUNT TABULATES THE ERRORS AS THEY ARE DETECTED,
SEVERE-ERRORS TABULATES THOSE ERRORS OF FATAL SIGNIFICANCE.

DECLARE (BUFFER, TEXT) CHARACTER,
  (TEXT-LIMIT, CARD-COUNT, ERROR-COUNT, SEVERE-ERRORS, PREVIOUS-ERROR) FIXED
;

/* NUMBER-VALUE CONTAINS THE NUMERIC VALUE OF THE LAST CONSTANT SCANNED,
DECLARE NUMBER-VALUE FIXED;

/* EACH OF THE FOLLOWING CONTAINS THE INDEX INTO V() OF THE CORRESPONDING
SYMBOL WE ASK:
  IF TAKEN = IDENT ETC.
DECLARE (IDENT, NUMBER, DIVIDE, EOFILE) FIXED;

/* STOPIT() IS A TABLE OF SYMBOLS WHICH ARE ALLOWED TO TERMINATE THE ERROR
FLUSH PROCESS. IN GENERAL THEY ARE SYMBOLS OF SUFFICIENT SYNTACTIC
HIERARCHY THAT WE EXPECT TO AVOID ATTEMPTING TO STAP CHECKING AGAIN
FLUSHED DOWN TO SOMETHING ACCEPTABLE TO A STOPIT() SYMBOL.
FAILSOFT IS A BIT WHICH ALLOWS THE COMPILER ONE ATTEMPT AT A GENTLE
RECOVERY. WHEN IT TAKES A STRONG HAND, WHEN THERE IS REAL TROUBLE
COMPILING IS SET TO FALSE, THEREBY TERMINATING THE COMPIILATION.

DECLARE STOPIT(100) BIT(1), (FAILSOFT, COMPILING) BIT(1);

DECLARE S CHARACTER; /* A TEMPORARY USED VARIOUS PLACES */

/* THE ENTRIES IN PRMASK() ARE USED TO SELECT OUT PORTIONS OF CODED
```



```

IF L >= WIDTH THEN RETURN STRING || SUBSTR(X70, 0, WIDTH-L);
ELSE RETURN STRING || PAD;
END PAD;

C_FORMAT: PROCEDURE(STRING, WIDTH) CHARACTER;
DECLARE (WIDTH,L) FIXED, STRING CHARACTER;
L = LENGTH(STRING);
IF L >= WIDTH THEN RETURN STRING;
ELSE RETURN SUBSTR(X70, 0, WIDTH-L) || STRING;
END C_FORMAT;

I_FORMAT: PROCEDURE (NUMBER, WIDTH) CHARACTER;
DECLARE (NUMBER, WIDTH, L) FIXED, STRING CHARACTER;
STRING = NUMBER;
L = LENGTH(STRING);
IF L >= WIDTH THEN RETURN STRING;
ELSE RETURN SUBSTR(X70, 0, WIDTH-L) || STRING;
END I_FORMAT;

ERROR:
PROCEDURE(MSG, SEVERITY);
/*
  IF SEVERITY IS NOT SUPPLIED, C IS ASSUMED */
DECLARE MSG CHARACTER, SEVERITY C;
ERROR_COUNT = ERROR_COUNTP;
/*
  IF LISTING IS NOT SUPPLIED, C IS ASSUMED */
IF LISTING = 0 THEN
  FORCE PRINTING OF THIS LINE */
IF CONTROL(BYTE(L)) THEN
  OUTPUT = I FORMAT(CARD_COUNT,4) || BUFFER || '!';
OUTPUT = SUBSTR(POINTER,1,1) || MARGIN_CHOP;
OUTPUT = *** ERROR, MSG || MSG;
  * LAST PREVIOUS ERROR WAS DETECTED ON LINE *
  PREVIOUS_ERROR = CARD_COUNT;
IF SEVERITY > 0 THEN
  IF SEVERE_ERRORS > 25 THEN
    DO;
      OUTPUT = '*** TOO MANY SEVERE ERRORS, CHECKING ABORTED ***';
      COMPILING = FALSE;
    END;
    ELSE SEVERE_ERRORS = SEVERE_ERRORS + 1;
  END ERROR;
  /*
  CARD IMAGE HANDLING PROCEDURE
  GET CARD:
  PROCEDURE:
*/

```



```

END;
/* BRANCH ON NEXT CHARACTER IN TEXT
DO CASE
  0 /*/
  /* CASE 0 */
  /* ILLEGAL CHARACTERS FALL HERE */ SUBSTR(TEXT, 0, 1));
  /* CASE 1 */
  /* BLANK */
DO; CP = 1;
DO WHILE BYTE(TEXT, CP) = BYTE(' ') & CP <= TEXT_LIMIT;
  CP = CP + 1;
END;
CP = CP - 1;
END;

/* CASE 2 */
DO FOREVER; /* A LETTER: IDENTIFIERS AND RESERVED WORDS */
  DO CP = CP + 1 TO TEXT_LIMIT;
    IF NOT LETTER OR DIGIT(BYTE(TEXT, CP)) THEN
      DO; /* END OF IDENTIFIER */
        IF CP > 0 THEN BCD = BCD || SUBSTR(TEXT, 0, CP);
        S1 = LENGTH(BCD);
        IF S1 > 1 THEN IF S1 <= RESERVED_LIMIT THEN
          /* CHECK FOR RESERVED WORDS */
          DO I = V_INDEX(S1-1) TO V_INDEX(S1) - 1;
            IF BCD = V(I) THEN
              DO; TOKEN = I;
              RETURN;
            END;
          END;
        END;
      END;
    END;
  END;
END;
/* RESERVED WORDS EXIT HIGHER: THEREFORE <IDENTIFIER> */
TOKEN = IDENT;
RETURN;
END;
END;
/* END OF CARD */
BCD = BCD || TEXT;
CALL GET_CARD;
CP = -1;
END;

```



```

/* CASE 3 */
DO; TOKEN = NUMBER; /* DIGIT: A NUMBER */
DO FOREVER;
  DO CP = CP TO TEXT_LIMIT;
    S1 = BYTE(TEXT, CP);
    IF S1 < "FC" THEN DO;
      IF PROB_FLAG THEN PROBLEM = PROBLEM || NUMBER_VALUE;
      RETURN;
    END;
    NUMBER_VALUE = 10*NUMBER_VALUE + S1 - "FO";
  END;
  CALL GET_CARD;
END;

/* CASE 4 */
DO; CALL CHAR;
  IF BYTE(TEXT, CP) = BYTE('*') THEN
    DO; TOKEN = DIVIDE;
      RETURN;
    END;
  /* WE HAVE A COMMENT */
  S1, S2 = BYTE('*');
  DO WHILE S1 = BYTE('*') | S2 = BYTE('*');
    IF S1 = BYTE('$') THEN
      DO; /* A CONTROL CHARACTER */
        CONTROL(S2) = CONTROL(S2);
        IF S2 = BYTE('T') THEN CALL TRACE;
        ELSE IF S2 = BYTE('U') THEN CALL UNTRACE;
        ELSE IF S2 = BYTE('I') THEN
          IF CONTROL(S2) THEN
            MARGIN_CROP = TEXT_LIMIT - CP + 1;
          ELSE MARGIN_CROP = 0;
        END;
        S1 = S2;
        CALL CHAR;
        S2 = BYTE(TEXT, CP);
      END;
    /* CASE 5 */
    DO; /* SPECIAL CHARACTERS */

```



```

TOKEN = TX(BYTE(TEXT));
IF PROB_FLAG THEN PROBLEM = PROBLEM || SUBSTR(TEXT,0,1);
CP = 1;
RETURN;
END;

END; /* OF CASE ON CHARTYPE */
/* ADVANCE SCANNER AND RESUME SEARCH FOR TOKEN */
END SCAN;

/* TIME AND DATE */

PRINT TIME: (MESSAGE, T);
PROCEDURE MESSAGE, T;
DECLARE MESSAGE 1/360000; /* T MOD 360000 / 6000 || 00:00
MESSAGE = MESSAGE / 100; /* MOD 100;
T = T / 100; /* MOD 100;
IF T < 10 THEN MESSAGE = MESSAGE || 00;
OUTPUT = MESSAGE || 00;
END PRINT_TIME;

PRINT DATE_AND_TIME: (MESSAGE, D, T);
PROCEDURE MESSAGE, D, T;
DECLARE MONTH(11) CHARACTER(1), YEAR, DAY, M) FIXED;
DECLARE MONTH(11) CHARACTER(1), JANUARY, FEBRUARY, MARCH,
APRIL, MAY, JUNE, JULY, AUGUST, SEPTEMBER, OCTOBER,
NOVEMBER, DECEMBER;
MONTH FIXED INITIAL(2), 31, 60, 91, 121, 152, 182, 213, 244, 274,
365, 335, 366;
YEAR = D/10000 + 1900;
DAY = D MOD 1000;
IF (YEAR % 3) = 0 THEN IF DAY > 59 THEN DAY = DAY + 1; /* - LEAP YEAR */
M = 1;
DO WHILE DAY > DAYS(M); M = M + 1; END;
CALL PRINT_TIME(MESSAGE || MONTH(M-1) || DAY-DAYS(M-1) || 0, 0, 0);
END PRINT_DATE_AND_TIME;

/* INITIALIZATION */

INITIALIZATION:
PROCEDURE;
PAGE;
CALL PRINT_DATE_AND_TIME('TEACHER' || SROLE, INTERPUTER -- NAVAL, ' || 
POSTGRADUATE SCHOOL, DATE_OF_GENERATION, TIME_OF_GENERATION);
DOUBLE_SPACE;

```



```

CALL PRINT_DATE_AND_TIME ('TODAY IS ', DATE, TIME);
DOUBLE_SPACE;
DO I = 1 TO NT;
  S = V(I);
  IF S = '<NUMBER>' THEN NUMBER = I; ELSE
  ELSEOFILE = EOF;
  STOPIT(EOF) = EOF;
  IF S = '<IDENTIFIER>' THEN IDENT = I; ELSE
  IF S = '/' THEN DIVIDE = I; ELSE
  IF S = ';' THEN EOF = I; ELSE
  IF S = ',' THEN STOPIT(I) = TRUE; ELSE
;
END;
IF IDENT = NT THEN RESERVED_LIMIT = LENGTH(V(NT)); LENGTH(V(NT-1));
ELSE RESERVED_LIMIT = LENGTH(V(NT));
V(EOF) = EOF;
STOPIT(EOF) = TRUE;
CHARTYPE(BYTE(' ')) = 1;
DO I = 0 TO 255;
  NOT LETTER_OR_DIGIT(I) = TRUE;
END;
DO I = 0 TO LENGTH(ALPHABET) - 1;
  J = BYTE(ALPHABET, I);
  TX(J) = 1;
  NOT LETTER_OR_DIGIT(J) = FALSE;
  CHARTYPE(J) = 2;
END;
DO I = 0 TO 9;
  J = BYTE('0123456789', I);
  NOT LETTER_OR_DIGIT(J) = FALSE;
  CHARTYPE(J) = 3;
END;
DO I = V_INDEX(C), TO V_INDEX(I) - 1;
  J = BYTE(V(I));
  TX(J) = 1;
  CHARTYPE(J) = 5;
END;
CHARTYPE(BYTE('/')) = 4;
/* FIRST SET UP GLOBAL VARIABLES CONTROLLING SCAN, THEN CALL IT */
CP = 0;
TEXT_LIMIT = -1;
TEXT = '';
CONTROL(BYTE('L')) = TRUE;
SY = 0;
FLAG(SY), VALFLAG(SY) = FALSE;
VALUE_OF(SY) = 0;
PROBFLAG = TRUE;
NUMBER_OF(SY) = 1;
CALL SCAN;
/* INITIALIZE THE PARSE_STACK(SP) = EOF; */
SP = 1; PARSE_STACK(SP) = EOF;

```


END INITIALIZATION;

```
DUMPIT: PROCEDURE; /* DUMP OUT THE STATISTICS COLLECTED DURING THIS RUN */
  DOUBLE SPACE;
  /* PUT OUT THE ENTRY COUNT FOR IMPORTANT PROCEDURES */
  OUTPUT = STACKING DECISIONS = CALLCOUNT(1);
  OUTPUT = SCAN = CALLCOUNT(3);
  OUTPUT = FREE STRING AREA = CALLCOUNT(4);
  FREELIMIT = FREEBASE;

STACK_DUMP:
  PROCEDURE;
  DECLARE LINE CHARACTER;
  LINE = PARTIAL_PARSE TO THIS POINT IS: 1;
  DO I = 2 TO SP;
    IF LENGTH(LINE) > 105 THEN
      DO;
        OUTPUT = LINE;
        LINE = X4;
      END;
    LINE = LINE || X1 || V(PARSE_STACK(I));
    OUTPUT = LINE;
  END;
  OUTPUT = LINE;
END STACK_DUMP;

LOOKUP: PROCEDURE(C);
  DECLARE C CHARACTER, I FIXED;
  DO I = 1 TO SY;
    IF SYMBOL(I) = C THEN RETURN I;
  END;
  RETURN 0;
END LOOKUP;

ENTER: PROCEDURE(C);
  DECLARE C CHARACTER;
  SY = SY + 1;
  IF SY > MAXSYM THEN DO;
    CALL ERROR('SYMBOL TABLE OVERFLOW ',2);
    CALL EXIT;
  END;
  SYMBOL(SY) = C;
  NUMBER_OF(SY) = 0;
  VALUE_OF(SY) = C;
  RETURN SY;
END ENTER;

TRACER: PROCEDURE(C) FIXED;
```



```

DECLARE C FIXED, L CHARACTER;
L = '';
DO I1 = MP TO SP;
L = L || V(PARSE_STACK(I1)) || ' ';
END;
OUTPUT = ' (' || C || ' )' || L;
END TRACER;

INDEX: PROCEDURE(C,D) FIXED; (L, J) FIXED;
DECLARE (C,D) CHARACTER, (L, J) FIXED;
L = LENGTH(D);
DO J = 0 TO LENGTH(C) - L;
IF SUBSTR(C,J,L) = D THEN RETURN J;
END;
RETURN 0;
END INDEX;

RANDOM: PROCEDURE(RANGE) FIXED;
DECLARE RANGE FIXED, RBASE FIXED INITIAL(1),
RMULT LITERALLY 671555;
RBASE = RBASE * RMULT;
RETURN SHR(SHR(RBASE,16) * RANGE, 16);
END RANDOM;

FIND_VALUE: PROCEDURE(LOW, HIGH, I);
DECLARE (LOW, HIGH, I, J) FIXED;
NUMBER_STRING = '';
DO J = LOW TO HIGH;
NUMBER_STRING = NUMBER_STRING || J;
END;
J = RANDOM(LENGTH(NUMBER_STRING));
VALUE_OF(I) = BYTE(NUMBER_STRING, J) - "F0";
END FIND_VALUE;

GET_VALUE_OF: PROCEDURE; (I, J, K, L) FIXED;
DECLARE DEC CHARACTER; (I, J, K, L) FIXED;
DO I = SYCNT+1 TO SY;
IF SYATFLAG(I) THEN DO;
IF FLAG(I) THEN DO;
J = RANDOM(LENGTH(NUMBER_OF(I)));
VALUE_OF(I) = BYTE(NUMBER_OF(I), J) - "F0";
END;
ELSE DO;
NUMBER_STRING = NUMBER_OF(I);
L = INDEX(NUMBER_STRING, I);
S = SUBSTR(NUMBER_STRING, C, L);
IF BYTE(S,0) < "F0" THEN DO;
I1 = LOOKUP(S);

```



```

K = BYTE(NUMBER_STRING,L+1) - "FO";
CALL FIND_VALUE_OF(I1), K, I;
END;
ELSE DO;
NUMBER_STRING = SUBSTR(NUMBER_STRING,L+1);
I2 = C;
DO J = 0 TO LENGTH(S)-1; J = "FO";
END;
IF LENGTH(NUMBER_STRING) = 2; THEN DO;
I1 = LOOKUP(NUMBER_STRING);
CALL FIND_VALUE(I2, VALUE_OF(I1), I);
END;
ELSE DO;
IF BYTE(NUMBER_STRING,J) = BYTE('') THEN DO;
I3 = INDEX(NUMBER_STRING,'');
NUMBER_STRING = SUBSTR(NUMBER_STRING,I3+1);
I1 = LOOKUP(SUBSTR(NUMBER_STRING,C,2));
I2 = I2 - VALUE_OF(I1);
I3 = INDEX(NUMBER_STRING,'');
I1 = BYTE(NUMBER_STRING,I3+1) - "FO";
IF I2 > 9 THEN I2 = 9;
CALL FIND_VALUE(I2, I1, I);
END;
ELSE DO;
L = INDEX(NUMBER_STRING,'');
S = SUBSTR(NUMBER_STRING,0,L);
NUMBER_STRING = SUBSTR(NUMBER_STRING,L+1);
IF BYTE(S,0) > "FC" THEN DO;
I1 = C;
DO J = 0 TO LENGTH(S)-1;
I1 = I1*10 + BYTE(S,J) - "FC";
END;
I3 = LOOKUP(NUMBER_STRING);
I1 = I1 - VALUE_OF(I3);
CALL FIND_VALUE(I2, I1, I);
END;
ELSE DO;
L = INDEX(NUMBER_STRING,'');
DEC = SUBSTR(NUMBER_STRING,0,L);
IF BYTE(DEC,0) = BYTE('') THEN DO;
DEC = SUBSTR(NUMBER_STRING,2);
I1 = LOOKUP(S);
I3 = 0;
DO J = 0 TO LENGTH(DEC)-1;
I3 = I3*10 + BYTE(DEC,J) - "FC";
END;
I4 = VALUE_OF(I1) - I3;

```



```

LINE = LINE || 11:
END;
IF J < SY_CNT THEN DO WHILE SUBSTR(PROBLEM, LINE_LENGTH, LENGTH(SYMBOL(J+1))) = SYMBOL(J+1);
LINE = LINE || SUBSTR(PROBLEM, LINE_LENGTH, 1);
LINE_LENGTH = LINE_LENGTH + 1;
END;

END;
DOUBLE_SPACE;
OUTPUT = LINE;
DOUBLE_SPACE;
END;
VERT;

HOR: PROCEDURE;
DECLARE LINE(6) CHARACTER, LINE_OUT CHARACTER;
DECLARE LINE_HOR '';
OUTPUT = LINE_HOR;
DO J = 1 TO 6;
LINE(J) = ' ';
END;
DO I = 1 TO 5;
CALL GET_VALUE_OF;
DO J = 0 TO SY;
OUTPUT = SYMBOL(J) || • VALUE_OF = • || VALUE_OF(J);
END;
I = 0;
DO J = 1 TO SY_CNT;
IF LENGTH(SYMBOL(J)) > L THEN L = LENGTH(SYMBOL(J));
END;
L = L/2;
DO J = 1 TO SY_CNT;
IF SYMBOL(J) = ANSWER THEN LINE(J) = LINE(J) || • || CFORMAT(., L);
ELSE DO;
IT = 0;
DO K = 0 TO LENGTH(SYMBOL(J))-1 BY 2;
I1 = I1*10 + VALUE_OF(LOOKUP(SUBSTR(SYMBOL(J), K, 2)));
END;
LINE(J) = LINE(J) || • || I_FORMAT(I1, L);
END;
END;
END;
DOUBLE_SPACE;
DO J = 1 TO SY_CNT;
OUTPUT = LINE(J);
IF J = SY_LINE THEN DO;
LINE_OUT = '';

```



```

DO K=1 TO 5; LINE_OUT || LINE_OUT || . . . || SUBSTR('-----', 0, L);
END;
OUTPUT = LINE_OUT;
END;
DOUBLE_SPACE;
END HOUR;
/* */

THE SYNTHESIS ALGORITHM FOR XPL

SYNTHESIZE:
PROCEDURE(PRODUCTION_NUMBER);
DECLARE PRODUCTION_NUMBER FIXED;
DECLARE COUNT_BIT(1); {TEMP, NUM} CHARACTER, DEC FIXED;
IF CCNTROL(BYTE('P')) THEN CALL TRACER(PRODUCTION_NUMBER);

DO CASE PRODUCTION_NUMBER;
;
/* <INTERPUTER> ::= <INTERPUTER STATEMENT> ; */ /* */
DO; IF MP = 2 THEN /* WE DIDN'T GET HERE LEGITIMATELY */ /* */
DO; CALL ERROR('EOF AT INVALID POINT', 1);
CALL STACK_DUMP;
END;
COMPILING = FALSE;
END;
/* <INTERPUTER STATEMENT> ::= <PROBLEM STATEMENT> */ /* */
DO; PROB_FLAG = FALSE;
SY_CNT = SY;
END;
/* <INTERPUTER STATEMENT> ::= <INTERPUTER STATEMENT> ; <PROBLEM STATEMENT>
/* */ /* */

DO; PROB_FLAG = FALSE;
SY_CNT = SY;
END;
/* <INTERPUTER STATEMENT> ::= <INTERPUTER STATEMENT> <RIGHT STATEMENT> */ /* */

```



```

;
/* <INTERPUTER STATEMENT> ::= <INTERPUTER STATEMENT> <DIRECTION> */
DO; IF VAR(SP) = 'VERT' THEN CALL VERT; ELSE
  IF VAR(SP) = 'HOR' THEN CALL HOR;
  PROB_FLAG = TRUE;
  SY = '0';
  PROBLEM = '0';
END;

/* <RIGHT STATEMENT> ::= <LEFT PART> <A_NUMBER> */
;

/* <LEFT PART> ::= <IDENTIFIER => */
DO; CALL ENTER(VAR(MP));
  COUNT = TRUE;
  NUMBER_STRING = '0';
END;

/* <A_NUMBER> ::= <A_NUMBER(> <DIGIT PART> */
;

/* <A_NUMBER(> ::= A_NUMBER(> <NUMBER> <IDENTIFIER> */
;

/* <A_NUMBER(> ::= VAR(SP); */
DO; COUNT = FALSE;
  TEMP = VAR(SP);
END;

/* <A_NUMBER(> ::= A_NUMBER(> <NUMBER> */
;

/* <NUMBER(> ::= FIXV(SP); */
DEC = FIXV(SP);

/* <DIGIT PART> ::= */
IF COUNT THEN DO;
  FLAG(SY) = TRUE;
  NUMBER_OF(SY) = DEC;
  VALUE_OF(SY) = DEC;
  VAL_FLAG(SY) = TRUE;
END;
ELSE DO;

```



```

I1 = LOOKUP(TEMP);
IF VAL_FLAG(I1) THEN DO;
  VAL_FLAG(SY), FLAG(SY) = TRUE;
  VALUE_OF(SY) = VALUE_OF(I1);
  NUMBER_OF(I1) = NUMBER_OF(I1);
END;
ELSE DO;
  VAL_FLAG(SY), FLAG(SY) = FALSE;
  NUMBER_OF(SY) = TEMP;
END;

/* <DIGIT PART> ::= <MINUS IDENTIFIER> <ARROW NUMBER> */
IF COUNT THEN DO;
  I1 = LOOKUP(TEMP);
  IF VAL_FLAG(I1) THEN DO;
    FLAG(SY) = TRUE;
    VAL_FLAG(SY) = FALSE;
    I2 = DEC - VALUE_OF(I1);
    DO I = I2 TO FIXV(SP-1);
      NUMBER_STRING = NUMBER_STRING || I;
    END;
    NUMBER_OF(SY) = NUMBER_STRING;
  END;
  ELSE DO;
    VAL_FLAG(SY), FLAG(SY) = FALSE;
    NUMBER_OF(SY) = DEC || FALSE;
    END;
END;

/* <DIGIT PART> ::= <RIGHT PART> <PLUS NUMBER> <ARROW NUMBER> */
NUMBER_OF(SY) = NUMBER_OF(SY) || '+' || FIXV(SP-1);

/* <DIGIT PART> ::= <ARROW NUMBER> <MINUS IDENTIFIER> */
IF COUNT THEN DO;
  I1 = LOOKUP(VAR(SP-1));
  IF VAL_FLAG(I1) THEN DO;
    I2 = FIXV(MP) - VALUE_OF(I1);
    DO I = DEC TO I2;
      NUMBER_STRING = NUMBER_STRING || I;
    END;
    NUMBER_OF(SY) = NUMBER_STRING;
    FLAG(SY) = TRUE;
    VAL_FLAG(SY) = FALSE;
  END;
END;

```



```

ELSE DO;
  NUMBER_OF(SY) = DEC || FLAG(SY) = FALSE;
  VAL_FLAG(SY), FLAG(SY) = FIXV(MP) || VAR(SP-1);
END;

/* <DIGIT PART> ::= <ARRROW IDENTIFIER> <MINUS NUMBER> */ */

IF COUNT THEN DO;
  I1 = LOOKUP(VAR(MP));
  IF VAL_FLAG(I1) THEN DO;
    FLAG(SY) = TRUE;
    VAL_FLAG(SY) = FALSE;
    I2 = VALUE_OF(I1) - FIXV(SP-1);
    DO I = DEC TO I2;
      NUMBER_STRING = NUMBER_STRING || I;
    END;
    NUMBER_OF(SY) = NUMBER_STRING;
  END;
  ELSE DO;
    FLAG(SY) = VAL_FLAG(SY) - DEC || FALSE;
    NUMBER_OF(SY) = DEC || VAR(MP) || ' - ' || FIXV(SP-1);
  END;
END;

/* <DIGIT PART> ::= <ARRROW IDENTIFIER> */ */

IF COUNT THEN DO;
  I1 = LOOKUP(VAR(SP-1));
  IF VAL_FLAG(SY) THEN DO;
    FLAG(SY) = TRUE;
    VAL_FLAG(SY) = FALSE;
    DO I = DEC TO VALUE_OF(I1);
      NUMBER_STRING = NUMBER_STRING || I;
    END;
    NUMBER_OF(SY) = NUMBER_STRING;
  END;
  ELSE DO;
    FLAG(SY) = VAL_FLAG(SY) - DEC || FALSE;
    NUMBER_OF(SY) = DEC || FIXV(SP-1);
  END;
END;

/* <DIGIT PART> ::= <ARRROW NUMBER> */ */

IF COUNT THEN DO;
  FLAG(SY) = TRUE;
  DO I = DEC TO FIXV(MP);

```



```

NUMBER_STRING = NUMBER_STRING || I;
END;
NUMBER_OF(SY) = NUMBER_STRING;
VAL_FLAG(SY) = FALSE;
END;
ELSE DO;
  I = LOOKUP(TEMP);
  IF VAL_FLAG(I) THEN DO;
    FLAG(SY) = TRUE;
    DO I = VALUE_OF(I) TO FIXV(MP);
      NUMBER_STRING = NUMBER_STRING || I;
    END;
    NUMBER_OF(SY) = NUMBER_STRING;
    VAL_FLAG(SY) = FALSE;
  END;
  ELSE DO;
    VAL_FLAG(SY) = FLAG(SY) = TEMP || FALSE;
    NUMBER_OF(SY) = TEMP || FIXV(MP);
  END;
END;

/* <ARROW NUMBER> ::= - <NUMBER> */
FIXV(MP) = FIXV(SP);

/* <ARROW IDENTIFIER> ::= - <IDENTIFIER> */
VAR(MP) = VAR(SP);

/* <RIGHT PART> ::= <ARROW IDENTIFIER> <MINUS NUMBER> , <IDENTIFIER> */
IF COUNT NUMBER_OF(SY) = TEMP-1 || VAR(MP); ELSE
NUMBER_OF(SY) = TEMP-1 || VAR(MP);

/* <PLUS NUMBER> ::= + <NUMBER> */
FIXV(MP) = FIXV(SP);

/* <MINUS NUMBER> ::= - <NUMBER> */
FIXV(MP) = FIXV(SP);

/* <MINUS IDENTIFIER> ::= - <IDENTIFIER> */
VAR(MP) = VAR(SP);

/* <IDENTIFIER => ::= <IDENTIFIER> = */

```



```

}; <PROBLEM STATEMENT> ::= <EXPRESSION> <RELATION> <EXPRESSION> */  

;  

/* <EXPRESSION> ::= <TERM> */  

;  

/* <EXPRESSION> ::= <EXPRESSION> <+> <TERM> */  

;  

/* <EXPRESSION> ::= <EXPRESSION> <-> <TERM> */  

;  

/* <TERM> ::= <PRIMARY> */  

;  

/* <TERM> ::= <TERM> * <PRIMARY> */  

;  

/* <TERM> ::= <TERM> / <PRIMARY> */  

;  

/* <PRIMARY> ::= <NUMBER> */  

;  

/* <PRIMARY> ::= <IDENTIFIER> */  

CALL ENTER(VAR(NP));  

/* <PRIMARY> ::= <(2)> <EXPRESSION> */  

;  

/* <PRIMARY> ::= ANSWER */  

CALL ENTER(VAR(NP));  

/* <(2)> ::= ( */  

;

```



```

/* <-> ::= -      */
;
/* <+> ::= +      */
;
/* <RELATION> ::= =  */
IF PROB_FLAG THEN SY_LINE = SY;
/* <RELATION> ::= <  */
IF PROB_FLAG THEN SY_LINE = SY;
/* <RELATION> ::= >  */
IF PROB_FLAG THEN SY_LINE = SY;
/* <RELATION> ::= > = */
IF PROB_FLAG THEN SY_LINE = SY;
/* <RELATION> ::= < = */
IF PROB_FLAG THEN SY_LINE = SY;
/* <RELATION> ::= > = */
IF PROB_FLAG THEN SY_LINE = SY;
/* <RELATION> ::= > = */
IF PROB_FLAG THEN SY_LINE = SY;
/* <RELATION> ::= ?  */
IF PROB_FLAG THEN SY_LINE = SY;
/* <DIRECTION> ::= HOR */
;

```



```

; /* < DIRECTION > ::= VERT */ ;
;

END;
END SYNTACTIC PARSING FUNCTIONS
/* */

RIGHT_CONFLICT:
PROCEDURE (LEFT) BIT(1);
DECLARE LEFT FIXED;
/* THIS PROCEDURE IS TRUE IF TOKEN IS A LEGAL RIGHT CONTEXT OF LEFT */
RETURN ("C0" & SHL(BYTE(CI(LEFT), SHR(TOKEN,2)), SHL(TOKEN,1)
& "C6")) = C;
END RIGHT_CONFLICT;

RECOVER:
PROCEDURE;
/* IF THIS IS THE SECOND SUCCESSIVE CALL TO RECOVER, DISCARD ONE SYMBOL */
IF FAILSOFT THEN CALL SCAN;
FAILSOFT = FALSE;
DO WHILE ~STOPIT(TOKEN);
CALL SCAN; /* TO FIND SOMETHING SOLID IN THE TEXT */
END;
DO WHILE RIGHT_CONFLICT (PARSE_STACK(SP));
IF SP > 2 THEN SP = SP - 1; /* AND IN THE STACK */
ELSE CALL SCAN; /* BUT DON'T GO TOO FAR */
END;
OUTPUT = 'RESUME:' || SUBSTR(POINTER, TEXT_LIMIT-CP+MARGIN_CHOP+7);
END RECOVER;

STACKING:
PROCEDURE BIT(1); /* STACKING DECISION FUNCTION */
CALL COUNT(1) = CALL COUNT(1) + 1;
DO FOREVER: /* UNTIL RETURN */
DO CASE SHR(BYTE(CI(PARSE_STACK(SP)), SHR(TOKEN,2)), SHL(3-TOKEN,1) & 6) & 3;
/* CASE C */
DO; /* ILLEGAL SYMBOL PAIR */
CALL ERROR('ILLEGAL SYMBOL PAIR: ' || V(PARSE_STACK(SP)) || X1 || Y(TOKEN) || 1);
CALL STACK_DUMP;
CALL RECOVER;
END;

```



```

/* CASE 1 */
RETURN TRUE; /* STACK TOKEN */

/* CASE 2 */
RETURN FALSE; /* DON'T STACK IT YET */

/* CASE 3 */
DO; J = SHL(PARSE_STACK(SP-1), 16) + SHL(PARSE_STACK(SP), 8) + TOKEN;
I = -1; K = NC1TRIPLES + 1; /* BINARY SEARCH OF TRIPLES */
DO WHILE I + 1 < K;
L = SHR(I+K, 1);
IF C1TRIPLES(L) > J THEN K = L;
ELSE IF C1TRIPLES(L) < J THEN I = L;
ELSE RETURN TRUE; /* IT IS A VALID TRIPLE */
END;
RETURN FALSE;

END; /* OF DO FOREVER */
END; /* OF DO FOREVER */
END STACKING;

PR_OK:
/* DECISION PROCEDURE FOR CONTEXT CHECK OF EQUAL OR IMBEDDED RIGHT PARTS */
DECLARE (H, J, PRD) FIXED;
DO CASE CONTEXT_CASE(PRD);
/* CASE 0 -- NO CHECK REQUIRED */
RETURN TRUE;

/* CASE 1 -- RIGHT CONTEXT CHECK */
RETURN -RIGHT_CONFLICT (HDTB(PRD));
/* CASE 2 -- LEFT CONTEXT CHECK */
DO; H = HDTB(PRD) - NT;
I = PARSE_STACK(SP - PRLENGTH(PRD));
DO J = LEFT_INDEX(H-1) TO LEFT_INDEX(H) - 1;
IF LEFT_CONTEXT(J) = 1 THEN RETURN TRUE;

```



```

END;
RETURN FALSE;
END;

/* CASE 3 -- CHECK TRIPLES */

DC;
H = HDTB(PRDB) - NT;
I = SHL(PARSE_STACK(SP-1) - PRLENTH(PRDB)) * 8) + TOKEN;
DO J = TRIPLE_INDEX(H-1) TO TRIPLE_INDEX(H) - 1;
IF CONTEXT_TRIPLE(J) = I THEN RETURN TRUE;
END;
RETURN FALSE;

END PR_OK:
/* OF DO CASE */
/* */

ANALYSIS ALGORITHM
*/

```

```

REDUCE:
PROCEDURE:
DECLARE: (I,J,PRO) FIXED;
/* PACK STACK TOP INTO ONE WORD */
DO I = SP - 4 TO SP - 1;
J = SHL(J, 8) + PARSE_STACK(I);
END;
DO PPD = PRMASK(PRLENTH(PRDB)) & J = PRTB(PRDB) THEN
IF PR_OK(PRDB) THEN
DO; /* ALLOW REDUCTION */
MP = SP - PRLENTH(PRDB) + 1; MPPI = MP + 1;
CALL SYNTHESIZE(PRDTB(PRDB));
SP = MP;
PARSE_STACK(SP) = HDTB(PRDB);
RETURN;
END;
END;
/* LOOK UP HAS FAILED, ERROR CONDITION */
CALL ERROR('NO PRODUCTION IS APPLICABLE',1);
CALL STACK_DUMP;
FAILSOFT = FALSE;
CALL RECOVER;
END REDUCE;

COMPILE_LOOP:
PROCEDURE:
COMPILE = TRUE;

```



```

DO WHILE COMPILE; /* ONCE AROUND FOR EACH PRODUCTION (REDUCTION) */
DO WHILE STACKING;
  SP = SP + 1;
  IF SP = STACKSIZE THEN
    END;
    RETURN; /* STACK OVERFLOW *** CHECKING ABORTED *** , 2);
  END;
  PARSESTACK(SP) = TOKEN;
  VAR(SP) = RCD;
  IF PROBFLAG THEN PROBLEM = PROBLEM || VAR(SP);
  FIXV(SP) = NUMBER_VALUE;
  CALL SCAN;
END;

CALL REDUCE;
END; /* OF DO WHILE COMPILE */
END COMPILE_LOOP;

PRINT SUMMARY;
PROCEDURE;
DECLARE I FIXED;
CALL PRINT_DATE_AND_TIME ('END OF CHECKING ', DATE, TIME);
OUTPUT = CARD_COUNT || ' CARDS WERE CHECKED.';
IF ERROR_COUNT = 0 THEN OUTPUT = 'NO ERRORS WERE DETECTED.';
ELSE IF ERROR_COUNT > 1 THEN OUTPUT = ' ERRORS (' || SEVERE_ERRORS
  || ' SEVERE ERRORS WERE DETECTED.';
  ELSE IF SEVERE_ERRORS = 1 THEN OUTPUT = 'ONE SEVERE ERROR WAS DETECTED.';
  ELSE OUTPUT = 'ONE ERROR WAS DETECTED.';
IF OUTPUT = 'THE LAST DETECTED ERROR WAS ON LINE ' || PREVIOUS_ERROR
  || PERIOD;
  IF CONTROL_BYE('D') THEN CALL DUMPIT;
  DOUBLE SPACE;
  CLOCK(3) = TIME;
  DO I = 1 TO 3; /* WATCH OUT FOR MIDNIGHT */
    IF CLOCK(I) < CLOCK(I-1) THEN CLOCK(I) = CLOCK(I) + 8640000;
  END;
  CALL PRINT_TIME ('TOTAL TIME IN CHECKER ', CLOCK(3) - CLOCK(1));
  CALL PRINT_TIME ('SET UP TIME ', CLOCK(1) - CLOCK(0));
  CALL PRINT_TIME ('ACTUAL CHECKING TIME ', CLOCK(2) - CLOCK(1));
  CALL PRINT_TIME ('CLEAN-UP TIME AT END ', CLOCK(3) - CLOCK(2));
  IF CLOCK(2) > CLOCK(1) THEN /* WATCH OUT FOR CLOCK BEING OFF */
    OUTPUT = 'CHECKING RATE: ' || 6000*CARD_COUNT/(CLOCK(2)-CLOCK(1));
    || ' CARDS PER MINUTE.';
  END PRINT_SUMMARY;

```



```
MAIN PROCEDURE:  
  PROCEDURE;  
  CLOCK(0) = TIME; /* KEEP TRACK OF TIME IN EXECUTION */  
  CALL INITIALIZATION;  
  CLOCK(1) = TIME;  
  CALL COMPILEATION_LOOP;  
  CLOCK(2) = TIME;  
  /* CLOCK(3) GETS SET IN PRINT_SUMMARY */  
  CALL PRINT_SUMMARY;  
END MAIN PROCEDURE;  
CALL MAIN PROCEDURE;  
RETURN SEVERE_ERRORS;  
EOF EOF EOF
```


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(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)	2a. REPORT SECURITY CLASSIFICATION Unclassified
Naval Postgraduate School Monterey, California 93940	2b. GROUP

3. REPORT TITLE

A General Problem Describer for Computer Assisted Instruction

4. DESCRIPTIVE NOTES (Type of report and, inclusive dates)

Master's Thesis; June 1971

5. AUTHOR(S) (First name, middle initial, last name)

Ronald J. Wools

6. REPORT DATE June 1971	7a. TOTAL NO. OF PAGES 99	7b. NO. OF REFS 20
8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)	
b. PROJECT NO.		
c.		
d.		
9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)		

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Naval Postgraduate School Monterey, California 93940
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13. ABSTRACT

Currently in computer assisted instruction systems a number of problems are presented to each student during a problem session and each individual problem is specified by the author of the session. A better approach might be to provide the author with a language in which he can describe the general type of problem he wants his students to be taught and let the machine generate the specific problems. This would relieve the teacher of the task of writing out a whole series of problems for each general concept he wishes to teach. This thesis presents a subset of English and mathematical notation which the teacher can use to describe a general problem type. The PROBLEM DESCRIPTION PROCESSOR accepts the general problem description and produces a low level language which is used by the PROBLEM DESCRIPTION INTERPRETER to produce specific problems. This system works for fourth grade arithmetic problems and could be extended for use in other areas of instruction.

KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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Computer-Aided Learning						
Computer-Based Instruction						
Learning						
Problem Describer						
Teaching						
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